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# An assessment of domestic rice distribution for transboundary water-food management in Japan through virtual water trade

Sang-Hyun Lee<sup>1</sup>, Makoto Taniguchi<sup>1\*</sup>, Naoki Masuhara<sup>1</sup>, Yun-Gyeong Oh<sup>2</sup>

5 <sup>1</sup> Research Institute for Humanity and Nature (RIHN), Motoyama 457-4, Kamigamo, Kita-ku, Kyoto, Japan

6 <sup>2</sup> Institute of Agricultural Science & Technology, Chonnam National University, Gwangju, Republic of Korea

7 \*Correspondence to: Makoto Taniguchi (makoto@chikyu.ac.jp)

## 8 Abstract

9 The self-sufficiency ratio of rice in Tokyo was less than 5% but the national self-sufficiency ratio in Japan has reached over 10 90% in 2012. Accordingly, local rice distribution is a key factor for regional food security but also water resource management 11 because a significant amount of irrigation water was simultaneously used or saved in the production or consumption areas, 12 respectively, through rice distribution. This study's aim is to analyze domestic rice distribution, and assess the dependency of 13 prefectures on water resources within or outside the region through virtual water flows that indicate the embedded water in 14 food trade. The results show that significant amounts of water were transferred virtually from the Northern regions such as 15 Tohoku and Hokkaido to industrial and urbanized regions including Tokyo and Osaka through domestic rice distribution. In 16 particular, the outflow of virtual water from the Tohoku region was more than 3 billion m<sup>3</sup>/yr during 2000-2012, and it was 17 almost three times larger than the net flows of virtual water within the Tohoku region. In addition, increasing self-supply in 18 the main producing prefectures affected the changes in the entire rice distribution network. In particular, as the self-supply in 19 Shiga-the main producing prefecture sharing the Yodo-river basin with Osaka in the Kansai region-increases, the 20 dependency of Osaka on virtual water flows from outside the Kansai region rises. Thus, it is important to consider the link 21 between food and water through virtual water flow in trans-boundary water management, integrating not only water resource 22 boundaries such as river basins, but also food boundaries covering production and consumption areas.

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24 Keywords: Paddy rice; Domestic distribution; Virtual water trade; Food self-sufficiency; Japan

#### 25 1 Introduction

26 According to the FAO, rice consumption in Japan was 112.8 kg/capita/yr in 1961 and it decreased continuously to 58.7 27 kg/capita/yr in 2012. Although rice consumption has decreased, the average daily calorie intake of a Japanese person in 2012 28 was approximately 1,870 kcal/capita/day and approximately 30% was gained from rice. In addition, about 7.1 million tons/yr 29 of rice was consumed as food in 2012 and more than 90% of the total consumption was fulfilled by domestic production 30 (FAOSTAT, 2018). Therefore, rice production is regarded as the main factor for food security in Japan and rice self-sufficiency 31 has not dropped below 80 % since 1961 (MAFF, 2016). However, in terms of the regional balance of rice production and 32 consumption, rice has been produced intensively in prefectures in the northern area such as Hokkaido, Akita, Aomori, Niigata, 33 and Iwate, but other prefectures including mega cities such as Tokyo and Osaka have consumed significant amounts of rice 34 with very low self-sufficiency (MLIT, 2018). Accordingly, we can infer that a significant amount of rice has been distributed 35 among prefectures, which could affect food security and resource requirements in rice-cultivating prefectures. However, there 36 is no available data regarding the domestic distribution of rice in Japan. Thus, it is important to estimate domestic rice 37 distribution among prefectures through a reasonable approach such as the gravity model (Tinbergen, 1962; Pöyhönen, 1963; 38 Rodrigue et al., 2009). The gravity model is a representative empirical method for estimating bilateral trade flows between a





39 pair of countries considering spatial interaction such as economic mass and distance between them (Batra, 2006). The equation 40 in the gravity model mimics gravitational interaction as described in Isaac Newton's law of gravity, and this model provides 41 an estimate of the volume of flows of, for example, goods, services, or people between two or more locations. Since this model 42 was introduced to analyze international trade flows by Tinbergen (1962) and Pöyhönen (1963), it has been successfully applied 43 to flows of varying types such as migration, foreign direct investment, and more specifically to international trade flows 44 (Martinez-Zarzoso, 2003). In addition, there are a huge number of empirical applications in the literature on international trade 45 which have contributed to the improvement of the performance of the gravity equation (Wei, 1996; Bougheas et al., 1999; Egger, 2000; Martinez-Zarzoso, 2003; Antonucci and Manzocchi, 2006). The key strength of the gravity model is in 46 47 considering spatial interaction between traders. Spatial interactions cover a wide variety of movements, such as trips to work, 48 migrations, public facility usage, the transmission of information or capital, retail marketing activities, international trade, and 49 freight distribution (Rodrigue, Comtois, and Slack, 2009). The basic assumption behind many spatial interaction models is 50 that flows are a function of the attributes of the origins and destinations and the friction of the distance between them (Rodrigue 51 et al., 2009). In this study, we applied the spatial interaction based on distance between prefectures and production and 52 consumption of rice to the gravity model, and estimated the domestic rice distribution among prefectures. 53 Rice distribution could also be to related water management because most rice in Japan is cultivated under full irrigation in 54 paddy fields (MLIT, 2018), and the irrigation water may be considered as the water contribution to supplying rice to other 55 prefectures, and prefectures importing rice instead of producing could save irrigation water. To sum up, rice distribution could be bound up with water supply in exporting prefectures and water saving in importing prefectures; thus, it is important to bring 56 57 rice distribution into trans-boundary water management linking exporting and importing prefectures. However, water is hardly 58 tradable, making it difficult to integrate prefectures in terms of water resource management. Some integrated water 59 management focuses on various water resources within a water basin but the trans-boundary water management referred to in 60 this study is more related to interlinkages among prefectures through food trade. Therefore, we applied the concepts of the 61 water footprint (WF) and virtual water trade (VWT) to assessing the effects of food distribution on regional water management. 62 The WF is the volume of water needed to produce one ton of product in the region where the product is actually produced 63 (Chapagain and Hoekstra, 2004). The concept, indicating the water embedded in the trade of products, was developed and 64 introduced to an international audience at an expert meeting on VWT in 2002, which contributed to solving water shortages 65 in the Middle East (Allan, 2001; Hoekstra 2003). The VWT has been used for quantifying how much water was traded between 66 countries in a virtual form through food trade, and it has been suggested as a relevant tool for a national water policy (Schyns 67 and Hoekstra, 2014). In the past, national water strategies have considered the quantification of actual water use and the 68 allocation of water resources, such as surface or ground water, in the context of their neighboring countries. However, VWT 69 suggests a wider perspective by expanding the watershed boundary from a real watershed to a virtual area between the importer 70 and exporters; for example, the virtual water export from a nation is the sum of the virtual water export from domestic water 71 resources (Fader et al., 2011; Hanasaki et al., 2010; Lee et al, 2017). In various studies, the concept of VWT has been adapted 72 for assessing water security considering the effects of food trade. For example, Falkenmark and Lannerstad (2010) analyzed 73 the effects of future agricultural water deficits through quantifying the VWT requirement and revealed that it will be necessary 74 to double the VWT by 2050. Biewald et al. (2014) evaluated the trade-related value of blue water usage using VWT and found 75 that the international trade of food crops could save blue water worth 2.4 billion US\$ globally. In cases of VWT application 76 on national and local scales, Bulsink et al. (2010) used the VWT to explain the positive effects of food trade on the water 77 resilience in Java, Indonesia, and Dalin et al. (2014) quantified the volumes of VWT between provinces in China and other 78 countries through agricultural trade. Lee et al. (2016) evaluated the vulnerability of VWT using degree and eigenvector centralities that included both the volume and connectivity in VWT networks, finding that Asian countries such as Japan and 79 80 South Korea have a more vulnerable VWT structure than European countries do. In particular, the volume of virtual water imported through grain crops into Japan was 41.9 km³/yr for 1996 through 2000 (Oki et al., 2003). 81





82 Although VWT has been adapted to various scales of water research in terms of global, national, and local water securities, it 83 is difficult to apply VWT to regional water resource management including different water basins or aquifers because water 84 is basically regarded as a non-tradable resource and specific facilities such as pipelines are required for transferring water 85 between water basins. However, it is obvious that water is used for producing products and water management for production 86 could be related to the regions where the products are consumed; thus, regional VWT could have a relationship with trans-87 boundary water management including production and consumption areas. For example, Shiga, Osaka, and Kyoto share the 88 Yodo-river water; Shiga produces significant amounts of rice and exports it to Osaka and Kyoto. Accordingly, Shiga has used 89 a significant amount of irrigation water, some of which could affect water management in Osaka and Kyoto, but ultimately 90 irrigation water was used for supplying rice to Osaka and Kyoto. Therefore, trans-boundary water management linking 91 production areas to consumption areas could be considered, making the concept of VWT a useful indicator for integrating food 92 and water management. In particular, we focused more on trans-boundary water management on a regional scale through 93 internal and external VWT in each region. Additionally, the food security in production and consumption areas is related to 94 the domestic distribution of rice, which accompanied the changes in regional VWT. For example, Chiba is the main rice 95 producing area in the Kanto region and supplies rice to Tokyo and Kanagawa, which are high-demand rice consumption areas 96 in the region. Therefore, changes in rice self-supply in Chiba for local food security could affect the internal VWT in the Kanto 97 region, which is related to regional water management. 98 Accordingly, it is important to consider food trade in the context of trans-boundary water management, and this study estimated

- 99 domestic rice distribution among prefectures during 2000-2012 through the gravity model with various food-security scenarios.
- 100 Based on the estimations, we analyzed the internal/external VWT and assessed the dependency of prefectures including mega
- 101 cities such as Tokyo and Osaka on water resources in exporting prefectures.

#### 102 2 Materials and Methods

#### 103 2.1 Estimation of domestic rice distribution among prefectures considering spatial interaction

104 Domestic rice distribution could be considered the interaction of behaviors between producers and consumers. For example, 105 consumers buy products from producers providing good prices, and generally producers managing big markets can provide 106 good prices. In addition, the distance between consumers and producers may be a factor affecting the decision of consumers 107 and producers in terms of transportation cost or easy accessibility. To sum up, the distribution of products should be affected 108 by spatial interaction, for example, a consumer generally purchases goods from the closest biggest market. 109 In the case of food distribution, spatial interaction is related to food balance and distances between prefectures. These were 110 measured using the gravity model, which utilizes the gravitational force concept as an analogy to explain the volume of trade, 111 capital flows, and migration among the countries of the world (Roy and Thill, 2004). Rice food balance in Japan differs by 112 prefecture, as shown in Table 1. The largest amount of rice is produced in the Tohoku region located in the Northeast of Japan 113 including the Niigata, Akita, and Fukushima prefectures among others, and approximately 637 thousand tons/yr was produced 114 from 2000 to 2012, which was 34 % of the total rice production. Among the 47 prefectures, Niigata is the biggest rice growing 115 area, producing 479.6 thousand tons/yr between 2000 and 2012. However, only 130.1 thousand tons/yr was consumed in 116 Niigata; thus, even though we assumed that only people living in Niigata consumed rice produced in Niigata, about 73 % of 117 Niigata's total production was consumed by people living in other prefectures. The next main rice-producing prefectures were Hokkaido and Akita producing 472.3 and 397.9 thousand tons/yr, respectively. Tokyo is the representative prefecture in the 118 119 Kanto region and consumed 762.5 thousand tons/yr despite producing only 0.6 thousand tons/yr, which was the smallest 120 production among all prefectures. Therefore, food security in Tokyo was very low and most rice was supplied from other 121 prefectures. Kanagawa is also a big rice consumer in the Kanto region, consuming 515.0 thousand tons/yr but producing only

122 11.8 thousand tons/yr. Therefore, these prefectures need to import large amounts of rice from other prefectures, and in





(1)

particular Chiba and Tochigi might play the role of the main producers of rice in the region, producing 245.8 and 264.7 thousand tons/yr, respectively. Accordingly, we could infer that large amounts of rice might be transported from Chiba and Tochigi to Tokyo because Chiba and Tochigi are available to export rice, and they are close to Tokyo geographically. This interaction is regarded as a spatial interaction in the gravity model. Based on the food balance of production and consumption, and distances among prefectures, we analyzed the spatial interaction for the weighted rice distribution:

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 $SI_{ij} = AE_i \times RI_j \times r_{ij}^{-\alpha}$ 

- 129 where SI is the spatial interaction, i and j are prefectures, AE is the amount of rice available for exporting to other prefectures, 130 RI is the rice import requirement, r is distance between prefectures, and  $\alpha$  is the friction parameter. The distance among 131 prefectures (producer and consumer) is considered a friction factor in rice distribution; thus,  $\alpha$  is the friction parameter. 132 Actually,  $\alpha$  should be estimated through observed data; however, there is no data about the distribution of rice among the 133 prefectures, which is why we assigned 2 to  $\alpha$  for weighted distribution and 0 for non-weighted distribution in this study. As 134 we mentioned earlier, the distance between producer and consumer could have negative effects on distribution. Actually, real 135 distribution follows roads or trails but it is difficult to use real roads and trails for calculating distances because of the 136 complexity of roads types such as local roads, highways, and others. Accordingly, we applied the Euclidian distance and set 137 the point located in middle of each prefecture and calculated the straight-line distance between points using the ArcMap 138 program.
- 139 AE and RI represent the market size and purchasing power, respectively; thus, they affect the positive influence on rice 140 distribution. However, the export availability in main producing prefectures and import requirement in main consuming 141 prefectures could be changed by the rice self-supply ratio (SSR) that indicates the amount of consumed rice being produced 142 within the prefecture. For example, even if a prefecture produces significant amounts of rice, the availability of rice for export 143 could be low if a significant amount of rice is consumed within the prefecture. The choice of where to purchase is left to 144 consumers, but it could also be related to food security policy, for example encouraging the consumption of local food. For 145 example, if Kyoto prefecture sets a food security goal of increasing the consumption of rice produced in the prefecture, the 146 amount of rice transferred from Kyoto to other prefectures would be decreased, and also the inflow of rice into Kyoto prefecture may also be decreased. However, it is very difficult to set the exact SSR; therefore, this study analyzed the effects of each 147 148 prefecture's rice food security on the entire domestic rice distribution through applying various SSRs as scenarios. In addition, 149 the SSR could have a different meaning in production and consumption areas. For example, in a production area the self-150 sufficiency is determined by the amount of consumption because the amount of production is larger than consumption. 151 Therefore, when the SSR is set at 50 %, it means that 50 % of the total consumption is provided from rice produced within the 152 prefecture. However, in a consumption area where the production is smaller than consumption, a 50 % SSR indicates that 50% 153 of total production is consumed by people living the prefecture, as shown in Eqs (2-3).
- 154  $AE_i = DP_i(1 SSR_i)$  where  $DP_i < DC_i$  (2) 155  $RI_j = DC_j(1 - SSR_j)$  where  $DP_j > DC_j$  (3)
- where *DP* is rice production for domestic supply, *DC* is domestic consumption of rice,  $RI_j$  is the import requirement in prefecture (j),  $AE_i$  is the available export in prefecture (i),  $SSR_i$  is the self-supply ratio indicating the ratio of rice production supplied for consumption within the prefecture to total production in prefectures under-producing rice, and  $SSR_j$  is the ratio of rice supplied from within the prefecture to total consumption in prefectures over-producing rice.
- To estimate the weighted distribution by spatial interaction, first we calculated the weight value of *SI* between specific prefectures and applied it to *RI* to obtain the initial export of each prefecture, as shown in Eq (4). However, there was an error that indicated a difference between total export and the *AE* of each prefecture; therefore, we applied the initial export between prefectures as weighted values and calibrated the export between prefectures by multiplying the weighted values with the total available export in each prefecture, as shown in Eq (5). Finally, we iterated these processes, as shown in Eq (6) until the errors in Eq (7) reached less than 1 % for both *RI* and *AE* in every prefecture.





166	$Ex_{ij} = SI_{ij} \times (\sum_i SI_{ij})^{-1} \times RI_j$		(4)
167	$f^{1}(i,j) = Ex_{ij} \times (\sum_{j} Ex_{ij})^{-1} \times AE_{i}$		(5)
168	$f^{2n}(i,j) = f^{2n-1}(i,j) \times \{\sum_i f^{2n-1}(i,j)\}^{-1} \times RI_j$	(n>0)	(6)
169	$f^{2n+1}(i,j) = f^{2n}(i,j) \times \{\sum_{j} f^{2n}(i,j)\}^{-1} \times AE_i$	(n>0)	
170	$err_i = \sum_j f^{2n}(i,j) - AE_i$		(7)
171	$err_j = \sum_i f^{2n+1}(i,j) - RI_j$		

where  $Ex_{ij}$  is the export from a prefecture (*i*) to prefecture (*j*),  $SI_{ij}$  is the spatial interaction,  $RI_j$  is requirement of import in a prefecture (*j*),  $AE_i$  is the available export in prefecture (*i*),  $f^n(i, j)$  is the iteration function of export from a prefecture (*i*) to prefecture (*j*), and n is the number of iterations.  $err_i$  is the difference between the sum of simulated exports and AE in

175 prefecture (*i*), and  $err_i$  is the difference between the sum of simulated exports and *RI* in prefecture (*j*).

## 176 2.2 VWT through rice distribution

We applied the concept of virtual water to estimate VWT through rice distribution in Japan in the context of food and water management. First, we surveyed the regional rice WF based on water withdrawal and rice production. Water withdrawal for paddy rice is different in each prefecture because of climate, productivity, farming technology, and so on. Ministry of land infrastructure transport and tourism (MLIT) in Japan provides irrigation water withdrawal in rice paddy fields for the nine regions (https://www.e-stat.go.jp), as shown in Table 1. The Kansai region, including Shiga, Kyoto, Nara, Osaka, Hyogo, and Wakayama prefectures, withdrew 56 billion m<sup>3</sup>/yr of water in rice paddy fields from 2000 to 2012.

183 Water withdrawal includes not only water used in paddy fields but also return flows to rivers. In Japanese rice paddy fields, 184 70 % of the total water withdrawal was returned to rivers (Masumoto and Yoshida, 2014). Accordingly, 30 % of the total water 185 withdrawal was defined as irrigation water in this study. Figure 1 shows the regional rice WF based on production and water 186 withdrawal from 2000 to 2012. The minimum WF was seen in the Tohoku region (1505 m<sup>3</sup>/ton) and the maximum in Shikoku 187 (2253 m3/ton). Thus, cultivating rice in the Tohoku region could have a positive effect on national water security because of 188 the high water-use efficiency. However, we also need to consider yield as well. For example, the rice WF in the Kanto region 189 was 1672 m<sup>3</sup>/ton, which was smaller than other regions except for Tohoku, but the yield in the Kanto region was 5.0 tons/ha 190 which was the second smallest. Therefore, the Kanto region uses less irrigation water but more land is required. Tohoku 191 showed the smallest WF and the largest rice yield; thus, increasing rice production in Tohoku instead of other regions could 192 have a positive effect on national water and land savings. However, the increase of rice production in Tohoku may be a burden to regional water security despite national water saving; hence, we analyzed the VWT among regions based on rice WF and 193 194 distribution.

The excess rice production in a prefecture is transported to other prefectures as food supply and the water used for this excess can be regarded as a water contribution from producing prefectures to other prefectures through VWT. By contrast, importing rice from other prefectures could have positive effects on water saving in the under-producing prefecture. As described earlier, VWT indicates the water embedded in food trade; thus, it is calculated using the WF, as shown in Eq (8).

 $WWT_{ii} = WF_i \times Ex_{ii} \tag{8}$ 

- where  $VWT_{ij}$  is the amount of virtual water exported from *i* to *j* prefectures,  $WF_i$  is the rice WF in producing prefecture *i*, and
- 201  $Ex_{ij}$  is the amount of rice exported from *i* to *j* prefectures.





#### 202 3 Results and Discussion

#### 203 **3.1 Estimation of weighted rice distribution among the 47 prefectures through spatial interaction**

The domestic rice distribution between the 47 prefectures in 2000–2012 was estimated based on the spatial interaction by import requirement, available export, and distance among prefectures. First, the effect of the distance on rice distribution was analyzed by applying the distance as a weight factor in spatial interaction. For example, non-weighted distribution applied the spatial interaction excluding the distance factor, whereas weighted distribution considered all variables including the distance in spatial interaction. In addition, we analyzed the effect of rice food security in all prefectures by setting various SSRs.

209 In the case of non-weighted distribution, the rice was transported mainly between big exporters and consumers even if they 210 were far from each other, as shown in Figure A1 in Appendix A. For example, under a 20 % SSR scenario, the largest rice 211 distribution is seen in Tokyo, which imported 54.47 thousand tons/yr of rice from Niigata, and the next largest was Hokkaido 212 (50.98 thousand tons/yr). Osaka was also a big importer, and 35,4 thousand tons/yr of rice was imported from Niigata. In terms 213 of main producing prefectures, rice production and consumption in Niigata were 479.6 thousand tons/yr and 130.1 thousand 214 tons/yr, respectively. Therefore, 471.58 thousand tons of rice was available for exporting to other prefectures under a 20 % 215 SSR scenario, and Niigata's excess rice production was distributed to main consumers such as Tokyo and Kanagawa in the 216 Kanto region, Osaka and Kyoto in the Kansai region, and Aichi in the Chubu region, among others.

217 However, when the distance was applied as a friction factor in weighted distribution, the internal distribution within each 218 region was increased, as shown in Figure A2 in Appendix A. For example, under a 20 % SSR scenario, the distribution from 219 Hyogo to Osaka in Kansai region was increased from 33.13 thousand tons/yr to 55.96 thousand tons/yr by applying weighted 220 distribution, and the largest distribution was seen from Chiba to Tokyo, which was 99.39 thousand tons/yr, and both prefectures 221 are located in the Kanto region. The biggest change in weighted distribution is seen in the Kyushu region. Internal distribution 222 within the Kyushu region was smaller than other regions, and the biggest internal distribution was 56.7 thousand tons/yr from 223 Kumamoto to Fukuoka. However, a large increase was seen in the distribution among Saga, Fukuoka, Kumamoto, and 224 Nagasaki in the weighted distribution. For example, the amount of rice exported from Kumamoto to Fukuoka increased 225 from .567 thousand tons/vr to 5.04 thousand tons/vr under a 20 % SSR scenario, and weighted distribution from Saga to 226 Fukuoka also increased significantly by approximately 12 times the non-weighted distribution.

#### 227 3.2 Analysis of impacts of food security in prefectures on the entire rice distribution through various SSR scenarios

228 The regional food-security policy was a main factor in rice distribution, thus we set various SSRs representing food security 229 from 20 % to 100 % and analyzed the changes of weighted rice distribution among prefectures, as shown in Figures A2-A4 230 in Appendix A. As the SSR increased from 20 % to 60 %, the self-supply in each prefecture increased observably. The biggest 231 self-supply was seen in Hokkaido (167.370 thousand tons/yr) and Chiba (147.51 thousand tons/yr). In particular Chiba was 232 the main rice producer in the Kanto region; thus, the rice supply in Tokyo and Kanagawa, both located in the Kanto region, 233 was strongly dependent on Chiba's rice production. Therefore, increasing the SSR in Chiba could affect the internal 234 distribution within the Kanto region, and the amount of rice transported from Chiba to Tokyo was decreased from 99.39 235 thousand tons/yr to 54.28 thousand tons/yr by increasing the SSR from 20 % to 60%. Accordingly, Tokyo needs to import 236 more rice from other regions close by, such as the Niigata and Akita prefectures in the Tohoku region. In the Kansai region, 237 Hyogo was the main exporter to other prefectures such as Osaka and Kyoto, and when the SSR increased from 20 % to 60%, 238 the rice self-supply in Hyogo increased from 29.86 thousand tons/yr to 89.57 thousand tons/yr, and rice transported from 239 Hyogo to Osaka decreased from 55.96 thousand tons/yr to 34.13 thousand tons/yr.

240 Rice import is more significant in the main consumption areas in terms of food security; hence, we focused more on the

- 241 changes in rice distribution from applying distance and SSR in Tokyo and Osaka, which are strongly dependent on rice imports.
- 242 Tokyo is the biggest rice consumer and consumes 762.5 thousand tons/yr. However, only 0.6 thousand tons/yr was provided





243 from within Tokyo; thus, about 760 thousand tons/yr should be imported domestically. Figure 2 and Table 3 show the changes in rice imports in Tokyo. In the non-weighted distribution with a 20 % SSR scenario, Tokyo largely imported rice from Tohoku 244 245 and Hokkaido regions which are main producers of rice in the Northern area. However, when the distance among prefectures was applied as friction in the weighted distribution, Tokyo's imports from the Kanto region, which it belongs to, increased 246 247 significantly. For example, before applying distance as friction in the gravity model, Tokyo imported 111.7 thousand tons/yr from the Kanto region which increased to 252.7 thousand tons/yr in the weighted distribution with a 20 % SSR scenario. As 248 249 the rice SSR increased, Tokyo's dependency on the Kanto region decreased and more rice was imported from the Tohoku 250 region instead. In the weighted rice distribution with a 60 % SSR scenario, 190.9 thousand tons/yr was imported from the 251 Kanto region and it decreased to 108.1 thousand tons/yr in a 100 % SSR scenario. We infer the two reasons for these changes: 252 first, Tokyo increased its self-supply but the small rice production in Tokyo had little effect. The other reason is that the main 253 producers in the Kanto region increased their self-supply which was accompanied by a decrease in rice exports to other 254 prefectures even though they are close to Tokyo. However, the imports from the Tohoku region to Tokyo were increased by 255 the increase in the SSR. For example, 291.3 thousand tons/yr was imported from the Tohoku region in a 20% SSR scenario 256 and this increased to 492.2 thousand tons/yr by increasing the SSR to 100 %. The prefectures in the Tohoku region produced 257 several times more than their consumption; thus, even if the SSR was increased to 100 %, they could still afford to export rice 258 to other prefectures, in particular to Tokyo, which is closer than other consumer prefectures. 259 Osaka consumed 498.7 thousand tons of rice annually between 2000 and 2012 but only produced 22.6 thousand tons. Therefore, 260 the rice supply in Osaka is highly related to rice imports from other prefectures. Figure 3 and Table 3 show the changes in rice 261 imports to Osaka. In the non-weighted distribution with a 20 % SSR scenario, 157.7 thousand tons/yr, which was 32 % of the 262 total consumption, would be imported from the Tohoku region in the Northern area. However, when distance was applied to 263 weighted distribution with a 20 % SSR scenario, importing from the Tohoku region was decreased to 82.5 thousand tons/yr

but importing from prefectures in the Kansai region that Osaka belongs to was increased from 28.5 thousand tons/yr to 144.8 thousand tons/yr. When the SSR was increased from 20 % to 60% in all prefectures, Shiga and Hyogo increased their rice selfsupply, and rice imports from Kansai to Osaka decreased to 100.7 thousand tons/yr. Therefore, Osaka needed to supplement the amount of rice imported from the Kansai region and imports from the Tohoku region were increased to 122.4 thousand tons/yr. When the SSR increased to 100%, this trend became more serious and more rice had to be imported from Tohoku

269 (206.4 thousand tons/yr).

#### 270 3.3 Assessment of rice distribution effects on trans-boundary water management through regional VWT

- 271 3.3.1 Analysis of internal and external VWT in regions through domestic rice distribution
- 272 This study converted the domestic rice distribution to VWT. Regional VWT could be regarded as an important factor for trans-
- 273 boundary water management connecting rice production and consumption regions.
- Figure 4 shows the VWT among regions, and the weighted distribution taking the distance factor into account derived the
- 275 increase in internal virtual water flows within regions and the decrease of virtual water flows among regions. However, changes
- in the SSR caused varying situations in regional VWT. For example, as each prefecture tried to increase their self-supply rather
- 277 than rice trade by increasing their SSR, the internal VWT was increased; however, the VWT from Tohoku to the Kansai region
- decreased slightly. In the Kanto region, the increase in the SSR decreased the VWT from Hokkaido, but the VWT from Tohoku increased.
- 280 Table 4 shows more details of the internal and external VWT changes in each region for each SSR scenario. The largest internal
- trade of virtual water is seen in the Kanto region. Here, the internal VWT reached 1754 Mm<sup>3</sup> with the 20 % SSR scenario, and
- it increased to 2018 Mm<sup>3</sup> with the 100 % SSR scenario. The Kyushu region shows an internal VWT of 1387 Mm<sup>3</sup> with a 20 %
- 283 SSR, which was the second largest, and it increased to 1697 Mm<sup>3</sup> with a 100 % SSR. A small internal VWT is evident in
- 284 Hokkaido and Shikoku. However, the largest export of virtual water is seen in the Tohoku and Hokkaido regions. For example,





3229 Mm<sup>3</sup> of virtual water was exported from the Tohoku region through the weighted rice distribution with an SSR 20% scenario, and it decreased to 3052 Mm<sup>3</sup> when all prefectures were set to a 100 % SSR food policy. The largest decrease of virtual water export caused by an increase in the SSR is seen in Hokkaido, where it decreased from 1061 to 493 Mm<sup>3</sup>. In the case of virtual water import, the Kanto region imported the largest amount of virtual water (2755 Mm<sup>3</sup>/yr) which was about 37 % of the total virtual water import in Japan. The next largest region was Kansai, and 1683 Mm<sup>3</sup> of virtual water was imported from outside Kansai through weighted rice distribution with a 20% SSR scenario.

291 3.3.2 Trans-boundary water dependency in mega-prefectures such as Tokyo and Osaka through domestic rice distribution

Tokyo and Osaka imported a significant amount of virtual water with a high dependency on water resources in other prefectures; thus, VWT in these prefectures could strongly affect regional water management. For example, Osaka shares the Yodo-river basin with Kyoto, Nara, and Shiga. In particular, Shiga is the main rice producer and exports rice to Osaka. Therefore, the distribution of rice from Shiga to prefectures located in the Kansai or other regions could be important factors for transboundary water management. Currently the largest portion of the population lives in Tokyo and the rice import to Tokyo could be highly related to water resource management in prefectures located in the Kanto and other regions.

298 Accordingly, we analyzed the dependency on internal and external virtual water imports in Tokyo and Osaka. When the 299 distance was applied to rice distribution as a friction factor, the amount of rice distributed from the Kanto region to Tokyo 300 increased significantly. However, as the SSR increased from 20 % to 100 %, the dependency on water resources in the Kanto 301 region decreased and significant amounts of virtual water were transferred from the Tohoku region, as shown in Figure 5. For 302 example, 450 thousand m³/yr was imported from the Kanto region in a 20 % SSR scenario, and it decreased to 219 thousand 303 m<sup>3</sup>/yr with the 100 % SSR scenario. By contrast, 39 % of total virtual water imported to Tokyo was transferred from the 304 Tohoku region under the 20% SSR scenario but it increased to 66 % under the 100 % SSR scenario. Therefore, the effect of 305 an increase in food security in all prefectures could mean that Tokyo depended less on the Kanto region for water. In the case 306 of Osaka, water dependency on the Kansai region increased significantly in the weighted rice distribution with a 20 % SSR 307 scenario in comparison with the non-weighted scenario. For example, virtual water imported from the Kansai region to Osaka 308 increased from 78 thousand m<sup>3</sup> to 369 thousand m<sup>3</sup> by applying weighted distribution, which was 35 % of the total virtual 309 water imported by Osaka. Therefore, Osaka has a large influence on water management in the Kansai region and trans-310 boundary water management linked to Osaka's rice imports should be considered. In addition, as the SSR was increased from 311 20 % to 60%, virtual water transferred from Kansai to Osaka was decreased by 282 thousand m<sup>3</sup>/yr, and it dropped to 133 312 thousand m<sup>3</sup>/yr under the 100 % SSR scenario. However, virtual water imported from the Tohoku region increased to 374 313 thousand m<sup>3</sup>/yr, which was 2.8 times more than the virtual water imported from the Kansai region. Therefore, the dependency 314 of high consumption prefectures such as Tokyo and Osaka on regional water management could be affected by transportation 315 distance and SSRs in other prefectures. Hence, this study shows that regional water management should include not only water use in production areas, but also the entire rice distribution network and VWT including consumption areas. 316

#### 317 4. Conclusions

In Japan, the area under rice cultivation has decreased since 1960, with the area in 2016 being only 44% of that in 1960 (World Bank, 2018), and rice is likely to be more sensitive to global warming than other agricultural crops and livestock, and over 70% of prefectures in Japan recognize the warming effects on rice (Sugiura et al., 2012). The decrease in rice production could pose a serious problem for food supply in some areas, thus the Japanese national government set a policy for maintaining the level of the rice self-sufficiency ratio as close to 100% as possible (MAFF, 2015). However, the regional rice self-sufficiency ratio in main consumption areas such as Tokyo and Osaka, was less than 5%; thus, most of their rice supply is dependent on imports from other prefectures. This means that domestic rice distribution could have positive effects on food contribution in terms of





325 food security as well as water saving in consuming prefectures. By contrast, the supply of rice to other prefectures could be a burden to water and land resource management in the main producing prefectures such as Niigata and Akita. For example, a 326 327 significant amount of irrigation water is required in rice paddy fields compared with other crops. 328 Therefore, this study considered rice distribution from the perspectives of trade-offs between food and water security through 329 the food and virtual water trade. We analyzed the changes in domestic rice distribution by spatial interaction through the 330 gravity model and SSR scenarios, and found that the changes in SSRs in producing and consuming prefectures could affect 331 the entire rice distribution as well as the internal and external virtual water flows in each region. For example, in the Kansai 332 region, the increase in rice self-supply in Shiga and Hyogo caused a decrease in the export of rice to Osaka, and resulted in an 333 increase in Osaka's rice imports from outside of the Kansai region. Accordingly, the internal virtual water flows from the 334 Kansai region to Osaka decreased and Osaka became less dependent on water resources in Kansai. The regional water supply 335 for rice production in the Kansai region is less related to rice consumption in Osaka; thus, other purposes for regional water 336 use might be suggested by Osaka and these should be discussed between Osaka and the main producing prefecture in the 337 Kansai region, such as Shiga. Therefore, the results from this study provide useful information for regional water management 338 and the integration of consumption and production areas. 339 However, there are limitations; for example, the gravity model used for estimating domestic rice distribution could not be 340 validated because of the lack of observed data even though we attempted to follow a reasonable approach. Second, this study 341 only focused on rice distribution with no changes in total production and consumption; therefore, the self-supply scenarios 342 applied in this study did not involve additional production but only affected the self-supply ratio in total production or 343 consumption. Third, the regional difference in rice consumption was not considered because of lack of data. We assumed that 344 people in Japan consumed the same amount of rice per year even if they lived in different prefectures. 345 In order to overcome these limitations, we applied the gravity model that was well-known approach for estimating products 346 trade, and WF of rice was calculated through the reliable statistic data from Japanese government. In addition, we tried to 347 consider various situations in domestic rice distribution through SSRs scenario relating to food security policy. In spite of 348 these limitations, the attempt to estimate domestic rice distribution and apply it to regional VWT in this study may contribute 349 to developing a useful indicator connecting water and food management in a framework for bridging scientists and policy-350 makers such as the Water-Energy-Food Nexus, and emerging as an appropriate tool for accomplishing the sustainable 351 development goals. 352 353 Data availability: The results data for this study are freely available by contacting the corresponding author. 354 355 Author contribution: Sanghyun Lee, Makoto Taniguchi, and Naoki Masuhara conceived and designed the research; Sang-

Hyun Lee and Naoki Masuhara analyzed the data; Sanghyun Lee and Yun-Gyeong Oh contributed analysis tools; Sanghyun
Lee and Makoto Taniguchi wrote the paper.

358

359 **Competing interests:** The authors declare that there are no conflicts of interest regarding this publication.

360

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Region	Prefecture	Consump- tion	Produc- tion	Self- sufficient (Prod./Con.)	Region	Prefecture	Consump- tion	Produc- tion	Self- sufficient (Prod./Con.)
0		1000	1000	0/	U		1000	1000	0/
		tons/yr	tons/yr	70			tons/yr	tons/yr	%0
Chubu	Aichi	422.3	118.8	28%	Kanto	Chiba	351.2	245.8	70%
	Fukui	44.4	107.5	242%		Gunma	111.3	69.3	62%
	Gifu	114.7	94.0	82%		Ibaraki	164.6	301.2	183%
	Ishikawa	65.1	103.7	159%		Kanagawa	515.0	11.8	2%
	Mie	102.5	119.3	116%		Saitama	409.7	135.5	33%
	Nagano	118.5	165.3	139%		Tochigi	111.4	264.7	238%
	Shizuoka	208.8	71.3	34%		Tokyo	762.5	0.6	0%
	Toyama	60.2	161.9	269%		Yamanashi	47.1	22.1	47%
Chugoku	Hiroshima	160.5	105.1	65%	Kyushu	Fukuoka	287.9	151.8	53%
	Okayama	108.5	135.9	125%		Kagoshima	93.0	91.8	99%
	Shimane	39.2	76.6	195%		Kumamoto	100.8	158.2	157%
	Tottori	32.4	55.7	172%		Miyazaki	62.3	76.9	123%
	Yamaguchi	79.3	91.7	116%		Nagasaki	77.8	51.1	66%
Kansai	Hyogo	312.4	149.3	48%		Oita	65.9	96.4	146%
	Kyoto	147.3	61.9	42%		Saga	47.0	112.4	239%
	Nara	77.0	37.1	48%	Tohoku	Akita	57.7	397.9	690%
	Osaka	498.7	22.6	5%		Aomori	73.9	225.6	305%
	Shiga	79.7	133.3	167%		Fukushima	108.0	317.9	294%
	Wakayama	54.4	28.9	53%		Iwate	72.2	233.8	324%
Shikoku	Ehime	78.2	59.9	77%		Miyagi	131.7	302.5	230%
	Kagawa	55.1	57.4	104%		Niigata	130.1	479.6	369%
	Kochi	41.1	46.6	113%		Yamagata	63.4	310.8	490%
	Tokushima	42.7	49.8	117%	Okinawa	Okinawa	80.9	2.4	3%
Hokkaido	Hokkaido	303.8	472.3	155%	Total		7172.1	6585.9	92%

422 **Table 1** Annual rice production and consumption as food in the 47 prefectures from 2000 to 2012

423

## 424 Table 2 Water withdrawal in rice paddy fields

Destant		Water	withdrawal i	n rice paddy	fields (billio	n m³/yr)	
Regions	2000	2005	2009	2010	2011	2012	Average
Hokkaido	4.5	4.3	4.3	4.3	4.3	4.3	4.4
Tohoku	15.4	14.9	14.9	14.8	14.8	14.6	14.9
Kanto	8.0	7.7	7.7	7.6	7.6	7.6	7.7
Chubu	7.9	7.5	7.3	7.3	7.3	7.3	7.4
Kansai	4.1	3.9	3.9	3.8	3.9	3.8	3.9
Chugoku	4.4	4.0	4.0	4.0	4.0	3.9	4.0
Shikoku	2.4	2.1	2.1	2.1	2.1	2.0	2.1
Kyushu	7.3	6.9	6.9	6.9	6.9	6.9	6.9
Okinawa	0.1	0.2	0.2	0.3	0.3	0.2	0.2

Source: Ministry of Land, Infrastructure, Transport and Tourism (MLIT)

425





Importer	Exporters	Non-weighted import (1000 tons/yr)		v	Veighted impo (1000 tons/yr)	rt	
(prefecture)	(region)	SSR 20%	SSR 20%	SSR 40%	SSR 60%	SSR 80%	SSR 100%
	Kansai	28.5	144.8	125.0	100.7	70.4	32.3
	Chubu	65.5	99.6	96.9	93.0	87.1	77.7
	Chugoku	32.3	38.1	38.3	38.3	37.6	35.1
	Hokkaido	32.8	31.4	32.6	33.8	34.8	35.2
Osaka	Kanto	73.1	13.5	13.5	13.4	13.1	12.7
	Kyushu	51.4	20.2	21.0	21.9	23.1	24.6
	Okinawa	0.2	0.2	0.2	0.1	0.1	0.0
	Shikoku	14.9	23.1	22.2	20.7	17.7	11.3
	Tohoku	157.7	82.5	99.2	122.4	155.9	206.4
	Kanto	111.7	252.7	224.1	190.9	152.5	108.1
_	Chubu	100.1	72.8	66.9	59.5	50.3	38.7
	Chugoku	49.4	5.9	5.6	5.2	4.7	3.8
	Hokkaido	50.2	60.4	59.4	57.3	53.6	47.8
Tokyo	Kansai	46.0	6.3	5.4	4.3	3.1	1.7
	Kyushu	78.5	7.8	7.6	7.3	6.9	6.4
	Okinawa	0.3	0.1	0.1	0.1	0.1	0.0
	Shikoku	22.7	2.8	2.5	2.2	1.7	0.9
	Tohoku	241.1	291.3	328.2	372.9	426.9	492.2

427 **Table 3** Import of rice in Osaka and Tokyo from regions by non- and weighted distributions with SSR scenarios during 2000–2012

428

429 Table 4 Internal and external virtual water flows by region through domestic rice distribution during 2000–2012

Region (million n	ns n³/yr)	SSRs	Chubu	Chugoku	Hokkaido	Kansai	Kanto	Kyushu	Shikoku	Tohoku
Available wate	r resource	-	8529	3282	5633	3072	3927	6214	2767	8675
		20%	1017	485	142	798	1754	1387	227	884
Net internal	flow of	40%	1160	586	284	874	1830	1461	295	943
virtual w	ater	60%	1307	686	427	941	1900	1536	364	993
within a r	egion	80%	1460	788	569	996	1963	1612	436	1032
		100%	1621	894	711	1036	2018	1691	514	1061
		20%	1044	645	1061	267	363	527	354	3229
	Outflow	40%	900	544	919	191	287	453	285	3169
	to other	60%	753	444	777	124	217	378	216	3120
	regions	80%	601	342	635	69	154	301	145	3080
External flow		100%	440	236	493	29	98	223	66	3052
of virtual water		20%	1212	453	413	1683	2755	334	277	235
	Inflow	40%	1066	349	309	1596	2662	261	215	156
	from other	60%	918	245	205	1514	2572	189	153	90
	regions	80%	769	143	102	1435	2485	116	90	38
		100%	615	40	-	1357	2402	45	23	-

430













![](_page_14_Figure_4.jpeg)

![](_page_15_Picture_1.jpeg)

![](_page_15_Picture_2.jpeg)

![](_page_15_Figure_3.jpeg)

- 438 Figure 3 Annual import of rice in Osaka prefecture by non- and weighted distribution with SSRs during 2000–2012 (1000 tons/yr)
- 439
- 440

![](_page_16_Picture_1.jpeg)

![](_page_16_Picture_2.jpeg)

![](_page_16_Figure_3.jpeg)

![](_page_17_Picture_1.jpeg)

![](_page_17_Picture_2.jpeg)

![](_page_17_Figure_3.jpeg)

448 449

450

446 447

Figure 4 Annual virtual water flow among regions through domestic rice distribution during 2000–2012. The numbers on the inner circle

451 indicate the amount of virtual water traded (100 million m<sup>3</sup>/yr) and the numbers on the outside circle are the percentage from 0 to 1.

![](_page_18_Picture_1.jpeg)

![](_page_18_Picture_2.jpeg)

![](_page_18_Figure_3.jpeg)

## VIRTUAL WATER IMPORT(VWI) IN OSAKA

![](_page_18_Figure_5.jpeg)

![](_page_19_Picture_1.jpeg)

![](_page_19_Picture_2.jpeg)

ſ	Chinava	Ukinwa L255	0.945	1.145	1.806	0.728	1.80	0.230	1.064	L467	0.864	9960	5.377	1.548	0.625	1.261	0.26B	1.485	0.288	2.568	3.430	0.127	1.428	0.077	1987	1.752	0.817	1.063	1.24	0.600	0.487	0.523	4835	3.745	2.757	3,508
		Yanagata 0.83	0.63	0.76	8	1.48	ñ	0.15	0.71	0.97	0.57	100	3.57	L03	0.42	0.84	910	0.99	0.19	R.1	0.46	0.08	0.95 2.04	000	1.04	1.16	0.54	6.0	0.86	0.40	0.22	0.35	3.21	1.76 2.49	1.83	2.33
		Miyes	130	1.58	2,48	001	2.59	030	1.46	2.00	611	500	7.40	2.13	0.86	1.73	103	2.04	0.40	3.52	0.96	0.18	196 422	10.0	2.16	2.41	1.12	1.45	1.78	0.83	180	0.72	6.65	3.65	3.79	24.19
	qu	Diate 0.94	0.71	0.85	13	0.54	1.41	0.16	0.79	100	0.64	0.72	4.01	1.16	0.47	0.94	0.18	П	0.22	167	0.52	0.10	1.07	100	2171	131	0.61	0.79	0.97	0.45	0.36	0.39	3.61	2.80	13.26	202
	đ,	1.42	1.07	130	2.04	0.82	2.13	0.25	120	1.65	0.98	1.09	60.9	1.75	120	1,43	0.27	1.68	0.33	2.90	0.79	0.14	1.62 3.47	100	1.77	1.98	0.92	611	1.46	890	0.67	0.59	5.47	3.00	3.12	397
		Acmet 0.96	0.72	0.87	8 R	8	141	0.17	0.81	Ξ	900	10 M	410	L18	0.48	6.0	610	F13	0.22	967	0.53	010	1.09	10.0	6171	0.21	0.62	(80	0.99	0.45	0.37	0.40	3.09	1356 2.85	2.10	2.67
		0.77	0.58	0.70	111	0.45	911	0.14	0.65	060	0.53	0C0	3.30	0.95	0.38	0.77	570	160	0.18	1.57	0.43	0.08	0.88	000	960	1.08	0.50	0.65	0.79	0.37	0.36	0.32	10.60	1.63	691	2.16
		0.54 0.54	6.9	0.49	0.77	63	080	00	0.45	0.62	0.37		2.30	0.66	0.27	0.54	9 9	0.63	0.12	607	030	0.05	0.61	000	0.67	0.05	0.35	0.45	0.35	0.35	0.23	7.83	2.07	113	1.18	87 B
	- thomas	Nocta 0.52	039	0.47	0.74	030	0.77	600	0.44	090	036	070	2.21	0.64	0.26	0.52	6170	190	0.12	1.05	0.29	0.05	0.59	000	0.64	0.39	0.34	0.43	0.53	0.25	7.54	0.21	199	1.09	113	1.44
	×	0.0	0.52	0.63	001	0.40	101	0.12	0.39	0.81	0.48	5	2.97	0.86	0.35	69	5 5	0.82	0.16	1.41	0.3	000	620	8	0.87	0.97	0.45	0.58	0.72	0.33	0.27	0.29	267	207	1.52	161
		1.03	0.27	0.94	1.48	0.59	1.54	0.18	0.87	611	0.71	0.79	439	126	0.51	1.03	020	2	0.24	2.09	0.57	0.10	117	100	128	0.76	78.0	0.86	1.06	11.99	0,48	0.43	395	3.06	2.25	2.87
		69 G	0.45	0.55	0.86	0.3	0.0	0.10	0.51	0.09	0.41	80	2.56	0.74	0.30	0.00		0.71	0.14	13	0.33	0.06	0.68	60	52.0	0.80	0.39	0.00	8.63	0.29	0.23	0.25	2.30	13	131	1-67
		0.83	0.63	0.76	120	0.48	125	0.15	0.71	0.97	0.57	160	3.57	1.03	0.42	0.84	910	0.99	0.19	1.70	0.46	0.08	0.95 2.04	000	1.04	1.16	0.54	12.09	0.86	0.40	0.39	0.35	321	2.49	1.83	2.33
		1.05 Nagend	0.3	0.96	51	190	1.57	0.18	0.89	8	0.72	180	4.2)	13	0.52	1.05	8	128	0.24	2.13	0.58	10	2.56	0.01	1.31	0.78 1.46	80.0	0.88	108	0.50	0.41	0.44	4.03	3.12	230	2.30
	Ryust	0.0	6.0	0.72	01	0.40 26-0	118	0.14	0.67	16.0	0.54	C 190	337	0.97	0.39	69	9 9	0.93	0.18	1.60	2.15	8	0.89	8	0.98	110	4 II	000	0.81	0.38	0.31	0.3	3.03	235	1.73	2
		100 miles	0.02	118	98 T	0.75	19	0.23	6	8	0.80	0.0	5.52	1.39	0.64	6	0.25	8	03	2.63	1.72	013	315	60	191	8.8	0.84	1	81	0.62	0.0	0.54	497	385	2.83	8
		40 Killi	0.8	1.07	1 LG	0.00	12	0.21	10	13	0.81	16 U	1 5.0	1.4	0.50	11	20	13	0.27	2.4	3.2	95	1.3	8	6 1.4	2 3	0.7	0.9	13	0.5	0.4	0.4	6 45	35 28	2.9	8
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		0.75	0.57	690	1.08	0.44		0.13	0.64	0.88	0.52	0.58	323	0.93	0.38	0.76	510	0.89	5.78	1.54	0.42	80.0	0.86	000	094	1.05	0.49	063	0.78	036	0.35	0.31	2.90	1.59	1 991	2.11
		Stigs W	0.77	0.93	1.46	6 6 6	8	0.18	0.86	118	0.0	20	4.8	1.25	0.51	8		14.64	0.23	2.07	2.38	0.10	2.48	0.01	10	6 G 2	89 0	80	10	0.30	8 0.8	370	3.91	3.03	2.23	2.84
		0 sala 7.74	582	7.06	11.13	4.49	11.60	136	656	898	532	202	313	9.54	3.86	7.77	452	51.6	1.78	15.76	430	0.78	8.80	0.04	996	5.77	5.03	649	7.97	3.70	3.63	3.22	6.62	16.34	66.99	21.61
	Kansa	- 108 I	0.81	0.99	1.56	0.63	9	0.19	0.92	1.35	10.74	80	463	133	0.54	6 1	0.21	8	0.25	2.3)	0.00	0.11	1.23	0.01	13	1.51	0.0	160	Ξ	0.52	0.42	97-10	417	57 52 57	2.38	3.02
		Mie 130	860	611	1.87	0.76	195	0.23	011	12	090	100	5.58	191	0.65	8.82	0.25	1.54	030	2.65	0.72	0.13	3.18	10.0	1.63	182	0.85	109	134	0.62	0.50	0.54	5.01	3.75	2.86	3.64
		2.11 2.11	6	1.92	300	1	316	0.37	6	2.45	1.45	9	9.02	2.60	1238	212	0.41	2.49	0.48	63	111	0.21	2.40 5.15	100	2.63	2.94	1.37	1	217	101	0.80	0.88	811	4.85 6.28	463	5.89
		4,46	336	4.07	6.42	2.59	6.70	0.78	3.78	5.18	3.07	143	9.12	38%	2.23	4,48	980	528	1.03	90.6	2.48	0.45	5.08 10.91	0.02	5.57	333 623	2.90	3.74	4.60	2.13	2.09	1.86	17.19	9.43	9.80	15-41
	Holdaido	4.09 4.09	9	3.73	685	2.37	6.14	0.72	347	4.75	2.82	3.15	55.79	5.04	2.04	41	0.29	484	0.94	8.34	2.27	0.42	4.65	80	511	3.05 5.71	2.66	3.43	4.22	96 T	8	8	15.76	8.64	8.99	9 T
		Variaçãe ta	0.76	0.92	1,44	0.58	151	0.18	0.85	911	690	14.56	4.30	124	0.50	101	050	61.1	0.23	2.04	0.56	0.10	1.14 2.45	10.0	1.25	0.75	0.65	0.84	1.03	0,48	0.39	0.42	3.86	2.12	2.20	2.80
		1.41 0.41	031	0.37	0.39	0.24	0.61	000	0.35	0.47	0.38	10.0	1.75	0.30	0.3)	0.41	8	0.48	000	0.83	0.23	0.04	0.46	8	0.51	0.57	0.27	0.34	270	0.19	0.16	0.17	1-22	0.86	0.90	1.14
	Chagelou	0.49	0.37	0.45	120	0.29	0.74	600	0.42	0.57	2.19	570	2.12	19/0	0.25	0.50	6T0	0.59	11.0	101	0.27	0.05	0.56	000	0.62	0.69	0.32	0.41	150	0.24	0.23	0.21	161	1.05	601	138
		0kayarra L.38	101	1.26	61	(80	200	0.24	617	19.92	0.05	100	5.92	5	0.09	61	0.27	163	0.32	282	0.77	0.14	1.57	100	62.1	1.98	06.0	116	a.1	0.66	0.54	0.58	225	2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2	303	3.86
		2.18	19	199	3.14	126	327	0.38	21.01	2.53	1.50	891	9.34	2.69	1.09	2.19	0.42	2.58	0.50	4,44	121	0.22	2.48 5.33	100	2.72	3.04	1.42	183	2.25	1.04	0.85	160	8.40	4.61	4.79	603
		Varrante 0.66	0.30	0.60	0.95	80	6.0	34	0.56	0.77	997	80	284	0.82	0.33	0.67	3 3	0.78	0.15	1.35	0.37	0.07	0.75	000	880	0.92	0.43	0.56	0.68	0.32	0.36	0.28	2.55	6 8 1	1.45	1.85
		0.77	0.58	0.70	11 2	0.45	11.06	0.14	0.65	0.90	0.53	0.59	3.30	0.95	0.38	0.78	5	0.91	0.18	1.57	0.43	0.08	0.88	8	96.0	1.08	0.30	0.65	0.80	0.37	0.30	0.32	2.97	2.30	<del>1</del> 99	216
		3.05 3.05	230	2.78	4.38	14.25	451	0.54	2.58	3.54	210	5 12	13.05	3.76	1.52	305	60	3.60	0.0	6.21	1.69	0.31	3.47	00	3.81	27 7 7	85 1	2.85	3.14	ş. 1	1.18	1.27	11.74	6.4 9.09	6.03	8.5
		L'76	5 8	197	2.53	8	2.64	0.31	67	2.04	1.21	1.85	7.54	2.17	0.88	13	0.34 0.34	2.08	0.40	3.99	0.98	0.18	200	10.0	2.30	2.46	1.15	87	1.82	0.84	0.68	0.73	82.9	3.72 5.25	3.87	4.92
	Casha	Nigero 1.15	3 3	8 1	21.76	80	228	0.27	8	1.26	104	211	6.30	181	0.76	12	8	6	0.35	3.09	0.84	0.15	128	10.0	- F8	212	0.99	121	1.36	0.73	0.71	0.63	5.84	130	333	4.24
		0.83	0.62	11.96	611	0.48	1.24	0.15	0.70	0.96	0.57	1064	3.54	1.02	0.41	0.83	0.16	0.98	0.19	1.68	0.46 2.26	0.08	2.02	80	1.03	1.15	0.54	0.09	0.85	0.39	0.39	0.34	3.18	2.46	181	231
		8 2 1	83	138 1	214	0.86	224	0.35	1.36	1.73	1.08	112	6.38	1.84	0.74	13	0.29	F.92	0.34	3.04	0.83	0.15	3.64	0.01	18	2.08	0.97	1.25	1.54	0.71	0.38	0.62	5.74	3.15	3.27	416
		6 0.56	0.42	0.51	180	87	0.85	0.10	0.43	0.65	6.0 5	10.0	5 2.42	0.70	0.28	0.57		0.67	0.13	3 1.15	0.31	0.0	1 1.38	000	0.0	0.9	0.37	0.47	0.58	0.27	022	0.23	5 2.17	8 F F R	3 1.24	8
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Appendix

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	Niguta	0.4)	0.33	8	0.17	2.25	0.30	2.31	0.13	0.16	8 8	0.10	8.9)	0.16	8 8	0.02	0.22	00	0.92	328	0.02	0.94	6.73	000	0.14	6 10	0.07	0.04	80	0.05	0.05	800	11.93	419	1479	18.6	23.89	18.16
	Miyagi	60.0	0.06	0.14	0.04	0.22	0.05	0.24	0.04	0.04	0.02	0.03	734	0.04	000	1070	0.04	100	0.28	112	000	0.14	1.15	000	0.04	cm 100	0.02	10.0	0.02	0.02	100	100	21.41	5,40	7.67	24.19	4.03	23.62
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	Acred	0.03	0.03	90.0	10.0	0.07	0.02	60.0	0.02	0.02	1	0.02	12.79	0.02	000	000	0.02	000	0.06	61.0	000	0.03	0.19	000	0.03	0.02	100	100	8	10.0	100	100	23.11	13.56	0.72	2.95 2.95	0.94	230
	Ada	0.03	003	90.0	10.0	0.07	0.02	60.0	0.02	0.02	1 1	1070	491	0.02	000	000	0.02	000	0.07	0.21	000	0.03	0.23	000	0.02	0.02	100	100	3	100	100	100	10.60	10.85	1.02	5.49	1.26	5.16
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80	Kagawa	0.31	0.16	0.31	0.34	0.23	0.08	0.37	2.80	822	860 1.14	0.85	1.98	2.09	60.0	0.15	0.39	0.19	01.0	61.0	000	90.0	61.0	000	0.76	050	0.38	0.16	0.22	1.47	10.12	1.70	0.90	0.50	0.39	0.55	0.86	0.56
	Ehime	0.29	0.15	0.32	0.27	0.25	0.08	0.39	8.43	2.75	0.65	4.61	3.01	0.86	80	80.0	0.30	0.12	0.13	0.25	00	600	0.24	00 IO	336	57	2	0.55	0.83	11.99	E	11.02	1.24	0.71	0.51	6.22	8	0.74
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	Nugual	60.0	0.05	0.12	0.07	0.10	0.03	0.15	0.63	0.32	11.0	1.76	195	0.15	100	0.02	0.08	0.02	900	11.0	000	0.03	11.0	000	12.45	758	138	10.21	22.87	0.39	11.0	0.10	0.68	0.41	0.25	039	0.48	0.38
Kyshu	Miyazaki	60	600	0.10	0.07	0.08	8	0.13	0.63	0.32	0.0	8	9	0.15	8 8	0.02	0.08	88	50 00	010	8	8	60	8 8	463	810	11.44	0.93	8	0.63	0.13	0.13	0.52	0.31	0.21	0.31	0.40	030
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	Variaties	0.99	0.51	0.62	0.21	512	2.29	5	0.09	0.11		0.07	2.73	0.13	8 8	0.02	0.23	00	8	99	0.09	5	16.1	00 55	000	6	0.05	0.00	8	0.01	0.04	100	213	0.95	2.25	3 8	5.41	2.02
	Tokyo	9.22	3.63	6.22	2.85	20.02	14.64	11.97	1.47	1.76	0.67	117	0.41	1.88	0.34	0.33	2.78	0.39	616	0 <b>1</b> 9	690	310	42,93	3.66	1.64	137	0.86	0.47	0.57	0.80	0.65	0.68	40.21	19.90	6 05 1 2	9 (F) 19 (F)	51.19	30.98
	idite.	0.24	0.14	0.32	0.08	0.8	0.3)	0.64	0.05	0.0	8.0	0.05	67	0.0	0.0	0.01	0.0	0.01	8 8	151	0.0	8	30.47	0.0	0.05	0.05	0.03	8,0	8.0	0.03	0.0	8, 8,	4.51	5	30.35	5.68	3.66	6.0)
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	Iturak	11/0	0.23	0.47	0.14	121	036	0.89	01.0	0.12	000	60.0	7.75	0.12	0.02	0.02	0.16	0.02	8.45	0.00	0.06	2.33	97 39	0.00	0.12	01.0	0.06	0.04	0.04	0.05	0.04	0.04	2.49	3.06	28	10.06	12.10	9.18
	Gurra	0.9)	0.40	0.81	0.17	17	0.52	8	0.10	0.12	8 8	0.05	471	0.13	8 8	0.02	0.3)	8	141	429	0.05	417	9.58	0.0	0.10	800	0.05	0.03	0.04	0.05	0.04	0.04	4.73	167	7.67	4.4	36.75	5.65
	Chhu	18	0.87	8	0.62	4.45	1.94	3.05	0.40	0.46	0.18	0.32	22.78	0.47	8	0.08	0.64	60	49.17	613)	0.30	806	24.46	0.05	0.46	80	0.24	0.13	0.16	0.21	0.17	0.13	17.09	3.89	27.30	19.53	26.19	17.65
	dayarra	1.43	0.56	0.79	3.09	170	0.29	1.03	1.00	1.76	0.53	0.57	395	2.83	193	1.28	1.82	5.78	0.28	0.52	100	0.16	150	0.04	9970	0.55	0.37	91.0	0.21	0.62	039	0.67	1.96	1.05	660	128	2.16	131
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	Kyoto	338	2.07	3.44	4.41	192	0.56	3.71	6	4.42	182	660	8.45	3184	0.97	2.91	14.28	0.81	0.55	1.08	0.02	0.36	114	000	1.09	083	0.53	0.27	0.34	0.85	138	0.76	4.58	2.41	2.23	286	537	3.08
	Nyago	5.3)	8.5	3.68	6.43	3.46	F 08	6,3	10.6	233	4.04	3.85	21.02	29.86	1.25	\$.08	10.87	2.33	611	234	0.03	0.72	2.41	0.00	3.96	2.95	187	0.92	8	3.0	8.98	3.38	19/01	5.72	486	447 (F 9	11.54	6.86
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	Totor	0.17	0.0	0.24	0.16	0.14	100	0.26	1.48	10.28	5.95	0.43	1.25	1.40	0.00	0.05	0.23	0.05	800	8 8	000	88	01	000	0.37	0.25	0.15	0.08	8	0.35	0.60	0.34	0.39	0.33	0.24	0.34	0.56	0.36
Chugoda	Stimano	0.12	0.15	0.16	0.10	0.11	8	0.19	12.54	189	617	2.18	( <del>1</del>	0.41	8	0.0	0.13	88	90 G	010	8	8	0.10	8 8	9	8 CP (0	0.34	0.00	0.29	0.86	0.37	0.41	0.39	0.34	0.23	0.34	0.49	0.34
	kayarna	90	9610	0.81	98	0.53	0.16	0.93	8.82	19.92	8 8	2.05	4.74	8 5	910	0.28	680	0.27	0.22	970	0.01	0.13	0.44	88	8	1	0.73	93	0.48	53)	6.38	1.73	218	8	26.0	8	2.07	13
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	Shinok	12.55	2.85	3.71	2.26	15.94	14.25	7.57	0.67	0.88	0.34	0.30	16.42	100	0.23	0.21	2.07	0.23	87	2.00	0.30	14	7.04	3.11	0.67	0.50	0.35	0.0	0.23	0.36	0.32	0.31	11.23	6.5	9.72	9.02	21.16	9.61
	Nagaro	2.75	2.62	3.36	0.57	21.76	1.73	11.04	0.23	0.31	0.12	0.17	6.55	0.37	900	0.07	0.75	0.06	5 5	2.53	0.05	1.60	3.41	0.00	0.22	0.18	11.0	0.06	80.0	0.12	0.11	01.0	5.36	2.38	4.72	4.10	17,38	499
	Mie	8.21	3.05	8	18.82	1.97	0.85	6.2	0.81	8 8	80	0.30	6.21	22	2.49	Ξ	9.18	96.0	0.39	108	0.02	0.37	1.07	00	0.61	8 6	0.33	0.16	0.30	0.44	0.55	0 69 0 69	3.45	2	8 1	234	4.55	2.45
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		40	0.03	0.05	00	0.06	00	0.04	100	0.08	0.45	0.21	800	2.43	0.72	0.05	0.01	8	0.04	10.0	0.01	10.0	8	8 8	0.05	8	9	96.0	3.96	242	36.28	8	0.45	0.23	0.07	0.42	0.24	0.13	0.30	0.35	00
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		Tokyo	5.83	3.72	2.53	9.11	195	11.11	8.41	13.88	1.05	149	0.20	1.05	67.73	101	0.33	100	236	0.20	123	5.56	2	16.83	21.15	0.36	2112	152	157	0.36	0.95	0.71	0.49	0.57	0.55	60.05	8X3)	34.65	49.17	8	000
1961		Tochigi	0.07	0.05	0.01	0.14	00	0.34	008	0.3	8	8	8 8	80	108	0.02	8	8 8	00	8	0.42	0.36	11-0	0.43	61.40	8	3 8	000	88	8 8	0.02	100	3 3	8	10.0	2.91	8	10.76	2.99	7.04	8
	9	Saturna	139	1.06	0.77	2.14	0.44	11.8	22	5.35	0.26	0.37	870	0.25	16.18	0.25	0.08	0.04	090	0.05	298	8.05	8	SF()	8F (J)	100	150	0.34	0.36	0.09	0.22	0.17	610	0.13	0.13	22.14	9.12	31.63	18.11	80.25	0.02
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	Karsa	Oak	10.0	20.8	44	00 1	25.2	89	8	14.3	6.31	160		417	33.8	34.0	13.5	10.5	35.9	6.8	137	18.0	2	0.80	6.2	8	1 6	3.75	4.73	6 6	9.6	2.05			7.47	27.13	140	111	14.2	25.9	0.14
		Nara	1.46	1.86	0.51	1.00	2.09	0.77	071	153	0.53	E .	0.47	0.39	3.69	1.47	0.56	22.35	330	130	21.0	01.0	120	11.0	0.62	000	10.0	0.39	0.47	0.10	0.33	020	0.30	0.35	1910	2.98	1.53	1.28	091	2.85	0.02
		Kyoto	167	8.51	12	g	2.00	Ę	8	3.85	<u>1</u>	336	9 9	680	7.17	8	37.13	9 7 7	10.83	0.38	0.27	0.18	60	618	12	8	8	90	0.85	0.18	0.61	0.38	8 9	8	0.95	5.97	3.06	2.39	3.04	585	8
		throgo	2.69	7.94	148	4.57	3.9)	2.41	630	5.97	65	2239	8	2.86	16.31	89.57	6.32	0.73	7.54	60	0.53	0.32	6	0.34	217	8	2,62	2.03	2.77	0.58	211	1.24	2.19	2.36	4.85	12.66	6.65	4 g	6.32	11.02	001
	Holdaido	Holdaido	0.13	0.17	0.07	0.32	0.07	0.30	0.06	0.55	11.0	0.13	900	0.13	167.37	0.07	0.02	100	0.10	10.0	0.19	80.0	0.89	600	160	000	0.17	0.20	0.2.0	11.0	11.0	010	0.04	0.05	0.04	0L.YZ	34.16	3.15	868	81.6	0.02
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-		Benci Y	0.06	91.0	0.03	0.13	90.0	0.07	100	21.0	090	489	12.84	0.22	0.67	0.45	0.05	100	11.0	0.02	0.02	10.0	0110	000	0.07	000	012	0.10	0.16	003	0.13	0.08	0.14	0.12	0.15	0.48	0.26	0.16	023	0.37	000
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![](_page_22_Picture_1.jpeg)

![](_page_22_Picture_2.jpeg)

![](_page_22_Figure_3.jpeg)