Reply to the referees for hess-2018-398

Article title: Assessment of food trade impacts on water, food, and land security in the MENA region
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Dear reviewer and editor,

thank you for considering the manuscript for publication in the HESS and in-depth review of the manuscript. We believe food trade bring important impacts on water-food-lands management in the MENA region. Therefore, this study focused on quantifying domestic water-lands savings by food trade, and we analyzed the virtual water trade in terms of volume and connectivity.
In reviewer's comments, we identified the main critiques directed towards the weak explanation of the situation of the MENA region, limitations and contribution of this study, and proposed methodology. We have made substantial changes to the manuscript to improve upon these points. For example, in revised manuscript, we added more reference studies for identifying the situation of the MENA region, and clarify the limitation of this study in terms of policy application for example, only historical data use and lack of geopolitical issues. In addition, we rewrote the methodology of eigenvector centrality with more references, and added more explanation about the difference between water saving and virtual water import. On the next pages you will find an overview of changes and a point-by-point reply to specific comments.
We appreciate again your thoughtful comments, and look forward to hearing your reply.

Kind regards, on behalf of all co-authors,
Sanghyun Lee

Overview of changes

We tried to revised the paper with your comments. Please find the overview of changes and point-by-point reply to specific comments. In terms of general comments, first we revised the introduction by adding more references about the situation of the MENA region, and added more explanation about the differences between water saving and virtual water import. In addition, we added more limitations in terms of spatial and temporal issues of VWT, and mentioned contribution and future works in conclusions. Finally, we checked entire manuscript and revised some paragraph and typo.

1. **We revised the introduction by adding more references about the situation of the MENA region.**
   Page 1: Line 27– Line 36
   Food security and water scarcity are urgent socio-economic and environmental issues in the Middle East and North Africa (MENA) region (Saladini et al., 2018), which are highly interlinked, and Water-Energy-Food Nexus has been suggested as a proper and integrated approach for resource management (Bazilian et al., 2011; Rasul, 2014; Mohtar and Daher, 2014; Lee et al., 2018). For example, food security in the MENA region has become complicated by increased risks owing to the geopolitical challenges and inability to satisfy needs with domestic production because of the lack of adequate arable land and water resources (Rastoin and Cheriet, 2010). In addition, food imbalance in the MENA region is forecast to reach 60 % in 2050 and food security in MENA region could be extremely compromised (Rastoin and Cheriet, 2010). Climate change could lead to more frequent occurrence of extreme climatic events in Mediterranean region, accompanying 50 % decrease of agricultural production by the end of the century (Porter et al., 2014). In particular, water saving through food trade can be suggested as a solution for mitigating groundwater depletion in the MENA region (Lezzaik et al., 2018).

2. **We added more explanation about the differences between water saving and virtual water import.**
   Page 4: Line 133– Line 144
   Food import is also related to domestic water and lands savings. In particular water saving has a different meaning from virtual water import. For example, Saudi Arabia imported wheat from various exporters and virtual water import indicates the sum of the products obtained from multiplying the quantity of imported wheat by the respective water footprint of each exporter. However, water saving indicates the amount of water needed to produce the same quantity of imported products domestically. Therefore, water saving by wheat import in Saudi Arabia is estimated by multiplying the quantity of imported wheat with the water footprint of wheat in Saudi Arabia.
   In this study, we applied green and blue water footprints of crops in each country in the MENA region, as shown in Table 1. However, the availability of water footprint data in the MENA region was limited in some cases. For example, the water footprint of wheat was available in all countries except for Bahrain. Lands saving has the same implication as water savings, thus we calculated lands saving using land footprint of each country in the MENA region, as shown in Table 2. The land footprint indicates the land requirement for producing 1 ton of crops, and it was calculated based on the harvest area and crop production data collected from FAOSTAT.

3. **We revised the entire part of section 3.1 to clarity the results.**
Page 6: Line 219– Line 238
This study considered trade-offs between food security and food trade in terms of national resource management. For example, the increase of domestic food products instead of imports of them could be one policy for food security but additional water and land for domestic products would be considered at the same time. In other words, food imports could contribute domestic water and land management, therefore, we estimated the national water and land savings by importing crops as shown in Table 3. In Saudi Arabia, blue water savings by barley, maize, and wheat imports were estimated to 5.0, 2.0 and 0.8billion m³/year, respectively. In comparison to the internal water resource of Saudi Arabia which is 2.4 billion m³/year as shown Table 1(World Bank, 2014), the water saving through import of barley, maize, and wheat could be considered as significant amount in Saudi Arabia. In the case of Egypt, most of the water saving occurred based on the imports of wheat and maize. Approximately 7.5 billion m³/year of blue water was saved by importing wheat. Specifically, the internal water resources in Egypt are only 1.8 billion m³/year (Table 1), therefore, water scarcity could be an issue for food security policy in Egypt. Lebanon was strongly influenced by the impact of crop import on land savings. Approximately 0.24 million ha could be saved by crop imports, comprising 36% of the agricultural area in Lebanon, that indicates that the crop trade in Lebanon has significant benefits in terms of land resources compared to water resources.
Food imports could be regarded as a negative factor in food security, and it is obvious that food security would accompany water and lands for domestic food products. These results showed that food imports could bring positive impacts on numerous water and lands savings in the MENA region. However, there are limitations of these results. First, water saving estimated in this study was based on the hypothetical situation that meat there were no international trade situation, and sometimes it was larger than the internal water resources in some countries such as Saudi Arabia and Egypt. Additionally, some crops are required for the specific type of climate but this study assumed that MENA region was suitable for cultivating maize, wheat, barley, and rice.

4. **In previous version, virtual water import diagram of only Lebanon was showed as a case but in revised version, we added virtual water import diagram of total MENA region and added explanation in section 3.3.**
Page 8: Line 289 –Line 297
From 2000 to 2012, both the volume and connectivity of VWT was changed. For example, the virtual water imported in the MENA region slightly increased and the VWT was distributed with more exporters in 2006, as shown in Figure 4. However, the volume of virtual water imported in the MENA region was increased more than 50 % from 2006 to 2012 but the distribution of VWT seemed to consistent. In case of Lebanon, VWT in Lebanon was strongly dependent on the USA, Argentina, and Australia. However, Lebanon expended the VWT in 2006 and Russian Federation, Turkey, and Kazakhstan, contributed to virtual water imports in Lebanon, as shown in Figure 4. Accordingly, the structure of VWT in Lebanon approached a distributed network. However, the VWT in 2012 showed that it was dominated by Ukraine and Russian Federation, though Lebanon imported more virtual water in 2012 than 2006.
Figure 4. Virtual water imports at the MENA region and Lebanon in 2000, 2006, and 2012

5. **We added more limitations in terms of spatial and temporal issues of VWT.**
   Page 9: Line 358– Line 363
   Third, there are spatial and temporal issues of VWT in the study. The VWT could be affected by geopolitical issues such as topography, and distances between importers and exporters. For example, the changes of exporting countries in the MENA region could be related to energy use for transporting products, thus trade policy should consider the economic benefit or cost of transportation. Therefore, the VWT should be discussed with geopolitical issues such as benefit and cost of transportation. In addition, VWT and water-lands savings by food trade in this study were calculated based on historical database, thus it was difficult to apply the results to future policy.

6. **We mentioned some future works in conclusions, for example, relationship between trade and energy part (energy use for transportation and food production).**
   Page 10: Line 383 – Line 398
   In summary, this study showed that the significant water in comparison to internal water resource could be saved by food trade in the MENA region, and policy makers can benefit by considering both the quantitative impacts of VWT and the structural changes of VWT, such as vulnerable expansion (or reduction) in the MENA region. For example, when a country in the MENA region set a plan for increasing food security, this country first should identify the amount of water and land savings that can be achieved by food import, and consider the trade-off between food security and food import. In addition, the stable trade could be a component for stable food supply in the MENA region, thus this study contributes to the understanding of the dependency on each trade partner for countries in the MENA region and can help with setting the food trade policy in terms of extension (or reduction) of trade partners and increase (or decrease) in volume of trade.
   However, this study only focused on food trade and water-land savings, thus energy part was not considered. The MENA region represents an extreme case globally in terms of water and energy resources, for example, 66% of the world's known crude oil reserves, but only 1.4% of the world's fresh water supplies is attributed to the region (Khater, 2001). The increase or decrease of water withdrawal for irrigation is related to the energy used for water extraction such as pumping surface or ground water. For example, 5 % or more of the total electricity consumption can be attributed to water pumping in Saudi Arabia (Siddiqi and Anadon, 2011). Energy use for food production and water supply could be the main factor in integrated resource management in the MENA region, and the lack of energy part was a limitation in this study.

7. **We checked entire manuscript and revised some paragraph and typo. Please find them in the revised manuscript.**

Point-by-point reply to specific comments

Reviewer's Comment: The water footprints of a given crop vary widely by country: for barley, green WF ranges from 193.6 to 6417.6 m3/ton. Adding together green and blue still gives a very wide range: ～8200 m3/ton in Libya vs 1000 m3/ton in Saudi Arabia. Are these numbers and their spatial variability realistic? Is it possible that producing barley in Libya consumes 8 times as much water as in Saudi Arabia? I don't imagine that potential ET varies that much over the region. Is the very wide range in WF because yields are so much higher in Saudi Arabia, but water consumption is assumed to be independent of yield? Some explanation is needed.

Answer: In this study, national water footprint of various crops from Mekonnen and Hoekstra, 2010 was applied. In my opinion, water footprint is affected by not only crop water requirement but also productivity. Thus, even if there is not much big difference in crop water requirement based on ETc, the productivity at each country in MENA region could be huge different. For example, the production and cultivated area of barley in Libya provided from World Bank were 191,641 ha and 94,107 ton, thus the productivity is 0.49 ton/ha but Saudi Arabia has 5.67 ton/ha (12,279 ha, and 68,366 ton). It was almost 10 times difference. Therefore, the difference of productivity could be one of main reason of wide range of water footprint.

Reviewer's Comment: I found the methods description for Eigenvector centralities confusing (L176-193). Please rewrite for clarity.

Answer: We tried to clarity the methodology for Eigenvector centrality and added some example researches.

Revision: Page 5: Line 194 – Page 6: Line 216

In general, connections to nodes which are themselves influential could make a node more influence than connections to less influential nodes (Newman, 2016), and eigenvector centrality can be used for measuring the influential connections (Ruhnau, 2000). For example, the concept of eigenvector centrality has been used by the Web search engine Google in order to rank Web pages (Berry and Browne, 2005; Bryan and Leise, 2006; Newman, 2016).

In VWT network, the eigenvector centrality could be used for identifying influential countries that could affect the entire network. In other words, the entire VWT can be affected by a few influential countries, and it is important to identify these countries for understanding and estimating the change of the entire structure of the VWT. An eigenvector centrality can measure the influence of each country in the entire VWT, and it is related not only to its own connection pattern but also to the connections of other countries to it. Therefore, a country is more influential if it is considered in relation to the countries that are influential themselves (Ruhnau, 2000). The eigenvector centrality assigns relative centrality to all of the countries in the VWT, based on the principle that connections to high-level centrality countries contribute more to the centrality of the countries compared to equal connections to low-level centrality countries (Ruhnau, 2000; Lee et al., 2016). Bonacich (1972) defined the centrality (x_i) of a node i as the positive multiple of the sum of adjacent centralities in links (or volume) between nodes (A_{ij}). Therefore, if we denote the centrality of vertex i by x_i, then we can allow for this effect by making x_i proportional to the average of the centralities of i's network neighbours (Newman, 2016),

$x_i = \frac{1}{\lambda}\sum_{j=1}^{n} A_{ij}x_j$ (8)

where λ is a constant. Defining the vector of centralities x = (x_1, x_2,...), we can rewrite this equation in matrix form as

$\lambda x = Ax$ (9)

This type of equation is solved using eigenvalues and eigenvectors, where A is a adjacency matrix of A_{ij}, and λ is a scalar, known as the eigenvalue associated with the eigenvector c defined as a column vector. Eigenvector centrality is determined by calculating the principal eigenvector that has the largest eigenvalue among all eigenvectors. A non-negative eigenvector with the maximal eigenvalue exists. We refer to a non-negative eigenvector ($x \geq 0$) of the maximal eigenvalue as the principal eigenvector, and we call the entry x_i the eigenvector-centrality of node (country) i (Ruhnau, 2000).

Reviewer's Comment: Some numbers are claimed to be significant, but without context. For example, Saudi Arabia saves 2 billion m3 per year by importing barley. Is that big number? Compared to what?

Answer: In previous manuscript, it was difficult to evaluate the results of water savings. Therefore, we added internal water resource of each country in MENA region into the Table 1, and compared the water savings with the internal water resource.

Revision: Page 6: Line 223 – Line 229

Answer: In Saudi Arabia, blue water savings by barley, maize, and wheat imports were estimated to 5.0, 2.0 and 0.8billion m^3/year, respectively. In comparison to the internal water resource of Saudi Arabia which is 2.4 billion m^3/year as shown Table 1(World Bank, 2014), the water saving through import of barley, maize, and wheat could be considered as significant amount in Saudi Arabia. In the case of Egypt, most of the water saving occurred based on the imports of wheat and maize. Approximately 7.5 billion m^3/year of blue water was saved by importing wheat. Specifically, the internal water resources in Egypt are only 1.8 billion m^3/year (Table 1), therefore, water scarcity could be an issue for food security policy in Egypt. Lebanon was strongly influenced by the impact of crop import on land savings.

Reviewer's Comment: The authors correctly note that it is important to identify countries that rely on only a few exporters. I'm not so sure that this means that countries with high dependence on one exporter should re-evaluate their policy, since I don't know enough about international trade strategy. Is there literature that can show that, historically, countries that rely on a single exporter are vulnerable to food sanctions? Can the authors cite historical precedent? Also, I found the shift in exporting countries from the US and Australia to other nations of potential importance to explain, both its causes and consequences. Is there more you can say about that in the paper?

Answer: We tried to search for historical precedent about impacts of trade structures on the international trade strategy. However, we could not find the specific examples. In terms of geopolitical issues and historical data use, we added some paragraph as limitations and future work parts.

Revision: Page 9: Line 358 – Line 363

Third, there are spatial and temporal issues of VWT in the study. The VWT could be affected by geopolitical issues such as topography, and distances between importers and exporters. For example, the changes of exporting countries in the MENA region could be related to energy use for transporting products, thus trade policy should consider the economic benefit or cost of transportation. Therefore, the VWT should be discussed with geopolitical issues such as benefit and cost of transportation. In addition, VWT and water-lands savings by food trade in this study were calculated based on historical database, thus it was difficult to apply the results to future policy.
