

Reviewer Comments and Responses

We would like to thank the reviewers for their very helpful comments. The major changes we have made include: a) adding some information about assessments carried out in Iran; b) making a clear and reasonable connection between the concepts of WF and VWC; c) adding Conclusion section; d) reorganizing the result section in such a way figures/tables are close to their references in the text; and e) re-writing some paragraphs to make them clear and understandable. We further clarified all issues raised by the reviewers. Please find the attached revised version of the manuscript as well as the supplementary documents. More details on how we responded to the comments are presented below:

Reviewer 1

A) Introduction can be improved by expressing some references of WF /VWC from Iran crops /cultivation systems, Water self-sufficiency cases etc.:

The authors agree with this point. There are really a few works done in Iran (especially in the study region) regarding the assessment of water resource sustainability using the concept of Water Footprint or other indices mentioned in this study. Almost all the works done in Iran focused on calculating the virtual water content of crops and the contribution of blue, green, grey, or even white WF components in one particular crop [1]. In fact, we are trying to have a comprehensive view for almost all available crops in the study region to be able to analyze the current condition in water resources sustainability point of view. Respecting this comment, some more details have been added as follows:

Page 2, line 51-55:

Merely a few comprehensive assessments are carried out in Iran regarding the evaluation of water resource management and sustainability using the water footprint concept as well as other indices like Water Self-sufficiency [13,14]. This is while other studies often focused their attention to calculating different components of water footprint in some particular agricultural products not the sustainability assessment of the water resource allocation to agricultural practices [1,15].

B) Explain what is WSS and give 1-2 references for its use for the water resources evaluation

Thanks for this point. Water Self-sufficiently (WSS) index is explained according to some references. This index can be used for water resources evaluation in both international and local scales. More details can be found in the manuscript.

Page 2, Line 68-70:

WSS is an indicator, which reflects the level a region is independent of other regions to meet its required water for producing its foods locally [8]. This indicator is used not only for international evaluation of water resources [14,15], but also for local water resource management [16].

C) This sentence belong to materials and methods but be more specific: did you estimated virtual water as the sum of green and blue water using the cropwat model?

The authors thank the reviewer for this point. As it is mentioned, the virtual water is calculated as the sum of the green and blue water only. This point is explained clearly in the manuscript as follows:

Page 4, line 107-111:

By using the CROPWAT model, it is possible to distinguish between the rainfall (green) and the irrigation (blue) sources of water used to produce one mass unit of a crop, and therefore, calculating the net virtual water flows, water self-sufficiency and WS would be possible for each share. In this study, the VWC of a crop is estimated as the sum of the green and blue VWC only.

D) Be careful with water footprint definition! you are estimated only the green and blue WF and not the gray one. Be accurate at this level of estimations and clearly state that you are not considering gray

footprint in your study (this is not mean that gray footprint does not exist...)

Thank you for this important technical point. Following this comment, the definitions of WF and VWC are clearly explained in the manuscript. First, the definition of water footprint is modified by adding the grey WF component. Then it is clarified that this study focuses only on the amount of local water resources used to produce crops not the total amount of water in the consumption chain. The WF of each county in the study region in agricultural products (i.e. crops+livestocks) will be published in the paper prepared by the authors in which the total volume of water within the production and consumption chain are considered for each county. The current manuscript mainly illustrates calculating the VWC of unprocessed crops to evaluate the sustainability of the productions in each county using some indicators such as WSS and WD. Regarding this point, the following part has been added to the manuscript:

Pages 3 and 4, lines 100-101 and 104-107:

... and the amount of water is needed to assimilate the pollution in order to maintain the existing ambient water quality within the standard levels.

It should be added that this study considers only the amount of water is used in land to produce unprocessed crops not the total amount of water used in their production and consumption chain. As a result, the virtual water content term is used to assess the agricultural sustainability of the water consumption of the province instead of water footprint term.

E) In the Water footprint assessment manual there is not any calculation method for VWC. You have to clearly relate the VWC with the blue and green WF in your study in order to use the WF estimations for the VWC

The authors agree with this point. Respecting this comment, Section 2.2.1 has been added to the manuscript to explain the methodology of the VWC.

F) This is not correct! please make a clear distinguish between Virtual Water and Water Footprint
Thanks for this comment. This issue has been modified as explained in comment (D).

G) Better formulation of the sentence

To make this issue clear, this part has been rewritten as follows:

Pages 6, lines 195-205:

in which WU refers to the total usage of both rainfall (green) and irrigation (blue) sources of water in crop production and WA is the total available water in a specific region. In this study, the amount of WU is computed by multiplying the calculated virtual water content of each crop (in m^3 / ton) to the total production of that crop (in ton). The WU in Equation (3) refers only to the amount of water consumed by agricultural practices not other usages of water (e.g., household, industry, mining, services, etc.). With identifying the characteristics of each meteorological station (such as geographical location and the amount of annual rainfall) within each county and using the concept of isohyet lines, WA is computed by using the ArcGis software. The required data to calculate these parameters is provided by Regional Water Company of South Khorasan province. Different situations of a region regarding WS values is shown in Table 1. As shown in this table, in the case of overexploitation, WS value exceeds 100 percent.

H) You mean figure 3? Please refer to tables and figures near the text. The reader cannot follow when you mention figures table "far away" from the text that mention them

Thanks for this point. The text and the figure/tables have been rearranged to be found easily by the readers.

I) potato is a fiber crop?

Thank you for this comment. As mentioned in the caption of Table 2, this category (fiber) includes Roots, Tubers and Fiber crops. For more convenience we only use the term of “fiber crops” to refer to this category in the text and graphs.

J) Better formulation

Thank you for this point. This paragraph/part has been rewritten to make it clear as follows:

Page 7, lines 223-240:

Due to the arid climate and the low annual precipitation (as described in Section 2.1), green virtual water (GVW) is a mere fraction of TVW in the study region. The largest proportion of GVW among the six categories belongs to the cereals with only 1.42%. This small contribution of GVW within the province have exerted enormous pressure on the South Khorasan aquifers. Table 3 compares different crop categories regarding their green and blue VWC. As shown in Table 4, the same crops have different VWC in different counties and therefore, it can be concluded that each county would be suitable for cultivation of particular types of crops. Regarding this issue, during the period of 2005-2014, it could be possible to save more than $346 \times 10^6 \text{ m}^3$ water annually without any reduction in the harvested lands by applying the proper cropping pattern in the region. This huge volume of water could be saved annually if spatial prioritization of crops based on TVW (as shown in Table 3) had been applied and the cultivation of some type of crops was moved to the counties with the minimum VWC or equally with the maximum water productivity. Table 4 depicts that there were remarkable differences in water productivity throughout the province. Using these results in agricultural practice could led to producing the same amount of crops by using by far less water, and consequently, the considerable pressure exerted on the groundwater could be substantially relieved (column 4 in Table 4).

Unfortunately, this great opportunity for saving a huge amount of water in such an arid region with limited water resources was lost due to ignoring the concept of virtual water by the local authorities.

K) Better formulation of the sentence

Thank you for this comment. The sentence/paragraph has been rewritten as follows:

Page 8, lines 250-259:

The proportion of each type of crops based on their cultivation areas and the amount of production are depicted in Figure 4. As shown in this figure, with a share of 7% in cultivated lands, vegetables account for 27% of crop production. At the province-level, cereals are the major type in both cultivated lands (61%) and crop productions (45%). This amount of production has led to export the surplus of 24,117 tonnage annually. It means that $68.31 \times 10^6 \text{ m}^3$ water transferred annually outside the boundaries of the province. However, the South Khorasan province is a net virtual water importer with regard to the other five crop types.. Based on the results of this study, these five crop types are responsible for importing $936.87 \times 10^6 \text{ m}^3$ water from outside the province. As shown in Figure 7, fruits have the largest share of the virtual water imported to the province with $423 \times 10^6 \text{ m}^3$ annually.

L) Delete the "around" you have estimate exactly the number

Thanks for this point. The needed correction has been applied.

M) Reorganize your results /discussion session in order to have the comment text near to the table figures you are mention

Thanks for the comment. The section has been reorganized in such a way that the reader can find the related figure/tables easily.

N) What is the unit of measurement?

Thanks for this point. It has been corrected. The unit is million cubic meter.

O) Figure 8 has to be closer to the text that describe it
Thanks for this point. It has been moved near the figure.

P) Are water resources enough to support a widespread shift to vegetable production?
Thank you for this important point. Similar to the other (semi-)arid regions, in the study region there are not enough water resources to meet all the needs. It means that the very limited available (and accessible) water should be allocated considering all the aspects. In agricultural section, as the main user of water, there was no specific reasonable and rational strategy for allocating water for different crop types. The simple criterion for allocating water was economic issues without any look to the sustainability of water resources. The main aim of this study is to answer this question: “How the local authorities can reallocate the limited available water to different crop types without any reduction in the farmers’ income in a sustainable way. During the study period, the authorities reallocated the limited water resources to the water-intensive fruit category only due to their high financial revenue. This is while their TVW is considerably higher than other categories’, especially vegetables. As, on the one hand, vegetables’ revenue per hectare is almost equal to fruits’ and, on the other hand, their TVW are considerably lower than fruit’s, it was more environmentally sustainable to allocate the water resources to this category. Regarding the above explanation the manuscript has been modified to include this issue as follows

Page 11, lines 337-341:

Regarding the depicted results in this figure along with the results shown in Table 3, vegetables are the most environmentally (low TVW) and second economically (high revenue per hectare) sustainable category. Therefore, it is worth to increase the cultivation area of this crop type. By applying this crop pattern, farmers would gain more profit by using the same amount of water or even less.

Q) Better formulation in figure 8
Thanks for the comment. The formulation of this figure has been edited.

R) A conclusion part is needed to summarize your findings and and evaluation of your method (indicators you used) for the water resources sustainability.
This comment is very crucial. Respecting this point, section “Conclusion” has been added as follows to summarize the study findings:

Pages 13-14, lines 377-404:

In the study region (South Khorasan province, Iran) due to the low precipitation and high rates of evapotranspiration, green virtual water (GVW) accounts for a small fraction of total virtual water (TVW). Besides, in this occasion, the national policy to achieving full self-sufficiency in producing all the agricultural produce has exerted an enormous pressure to groundwater aquifers. In line with this policy, overexploitation have occurred in most counties of the South Khorasan province. The results of this study show that there are significant differences in the productivity of same crop categories in different counties throughout the province mainly due to different climatic parameters. It is shown that if the spatial prioritization for harvesting different crop categories had been established by the local authorities, more than 346×10^6 m³ water could be saved annually in the agricultural practices within the province without any reduction in cultivation area. Although there was a considerable decrease in the cultivation area of some crops during the period of 2005-2014, this reduction in cultivation areas did not contribute to water saving. This was largely caused by the expansion of the water-intensive crops cultivation, namely fruits.

In addition, the Water Scarcity of counties within the province has been quantified applying some indicators in this study. The results show that almost all the counties are heavily exploited or even overexploited. In addition, there was an increasing trend in Water Scarcity of counties due to the

growth of cultivation of water-intensive crops, such as fruits, which led to an increase in water exploitation.

Considering the water-related problems in South Khorasan province, there is a crucial need to change management strategies for limited available water resources. For example, importing water-intensive crops instead of producing them in the province can alleviate the situation. Furthermore, the region authorities should understand food self-sufficiency concept correctly and consequently the meaning of the “development”. Unfortunately, the current agricultural practices in the province is neither environmentally nor socioeconomically sustainable. Importing foods from outside the borders of the province, in the national scale, instead of producing them locally can save a huge amount of water annually. The results of the study indicate that, in the sustainability point of view, importing cereals and fruits are of high priority not only due to their high consumption in the province but also for their high TVW.

Reviewer 2

A) A massive work has been done and therefore I recommend it for publication in its present format.
The authors appreciate your kind words.