Authors' responses to interactive comments on "Spatiotemporal responses in crop water footprint and benchmark under different irrigation techniques to climate change scenarios in China"

Dear Referee #1,

Thank you very much for your valuable comments and suggestions on our manuscript. We have provided our responses directly below each of the comments.

Anonymous Referee #1

General comments

1. One could divide WFP benchmarking techniques into two methods. Method 1 compares the WFP of different producers (or grid cells) within the same region, ranks them and sets a benchmark based on some percentile. Method 2 compares the WFP at each location under different management practices and sets a benchmark based on best practices (those resulting in the smallest WF). Method 2 is for example applied in the studies by Chukalla et al. (https://doi.org/10.5194/hess-21-3507-2017 and https://doi.org/10.5194/hess-19-4877-2015). The drawback of method 1 is that no matter what spatial scope one takes in grouping producers, within that scope there will still be variability from place to place (section 4.3.2.1 in https://doi.org/10.1016/B978-0-12-822112-9.00006-0). Rainfall, for example, shows strong spatial variability over short distances, such that a few producers in a larger area simply had more favourable local circumstances. Therefore, one can always question the comparability of producers that operate in different locations and the WFPs they achieve. Method 2 overcomes this drawback. In this manuscript method

1 is applied, although different irrigation practices are simulated. What are your reasons for determining the benchmarks based on method 2? Why don't you determine the benchmarks (also) based on method 1? You seem to have the data/simulations for that.

Response: We deeply appreciate your valuable comment. Sure, we acknowledge that three are two methods of establishing WF benchmarks (Hoekstra, 2013). The reason why we choose Method 1 instead of Method 2 is that we mainly explore the responses of large-scale WFs for two grain crops to future climate changes under specific irrigation technique, that is, each irrigation technique has its corresponding WF benchmarks. If Method 2 was selected, what we concerned about was the responses of WF to future climate change under the optimal tillage plus irrigation techniques which would result in the smallest WF. It is inconsistent with the current research objectives. This is also relevant to your General comment 2. Method 2 has the higher requirements on the setting and simulation of different agricultural management practices. However, we focus on only one agricultural management practice here, i.e., irrigation. If we chose Method 2, the calibration of different agricultural management practices would be the key. The existing data cannot meet these requirements for such a large-scale study. Therefore, we choose Method 1 to determine WF benchmarks. And we also realized that the application of Method 1 does have some limitations. We will add the consideration to Section 3.5 Discussion on the choice of two WF benchmarking methods and different agricultural management practices in combination with your Specific comment 13. The content is as follows.

"Three are two methods of establishing WF benchmarks (Hoekstra, 2013). Method 1 is based on yield accumulation statistical analysis. Due to the variability of WFs found across regions and among producers within a region, for each crop, we can select the WF of 20 % or 25 % of the producers with the highest water productivity as the WF benchmark (Mekonnen and Hoekstra, 2014). Method 2 is based on the available optimal technique analysis. We can compare the WFs at each location under different agricultural management practices and take the WF associated with optimal practice, which results in the smallest WF, as the WF benchmark (Chukalla et al., 2015). Both methods establish WF benchmarks based on the maximum reasonable water consumption in each step of the product's supply chain (Hoekstra, 2014). Method 1 is suitable for large-scale application. The differences in environmental conditions (such as climate) and development conditions should be considered comprehensively (Mekonnen and Hoekstra, 2014; Zhuo et al., 2016a). The drawback of Method 1 is that no matter what spatial scope one takes in grouping producers, within that scope there will still be variability from place to place even if the differences in regional environmental and development conditions are taken into account (Schyns et al., 2022). Method 2 is suitable for smaller scale and overcomes this drawback of Method 1 to some extent. While the Method 2's drawback is that it has the higher requirements on the setting and simulation of different agricultural management practices. We mainly want to explore the response of large-scale WF to future climate change under specific irrigation technique, that is, each irrigation technique has its corresponding WF benchmarks. And only one agricultural management practice, that is irrigation, is considered here. Therefore, we choose Method 1. If conditions permit, we strongly recommend that Method 1 and Method 2 be combined when establishing small-scale WF benchmarks. We can consider different agricultural management practices, such as irrigation, mulching techniques and so on. They can be combined to further determine WF benchmarks."

2. AquaCrop provides crop parameters sets for maize and wheat which are to some degree calibrated for the conditions of recent history. How do you make sure the model produces reliable results for ET and Y under climate change scenarios?

Response: We are very sorry for our unclear expression and use of incorrect words. To some extent, we guaranteed how evapotranspiration (ET) and yield (Y) will develop in the future at the current production level. First, we chose 2013, when the drought level came closest to the 15-year national average drought level from 2000 to 2014, as the baseline year. Second, the simulated Y per grid for each crop in 2013 was calibrated via scaling model simulation outputs to accord with the crop yield statistics data at the provincial level (NBSC, 2021), which was consistent with the widely used calibration method (Mekonnen and Hoekstra, 2011; Zhuo et al., 2016b, 2016c, 2019; Wang et al., 2019; Mialyk et al., 2022). For sure, the calibrated Y corresponded to the simulated ET. The crop parameters in model represent the existing agricultural production level. Climate is the only variable for future scenario analysis.

3. Micro-irrigation results in the smallest WFP and largest Y (Figure 3). Yet how feasible (and profitable) is micro irrigation in maize and wheat production in practice? Is it commonly applied for these crops in some parts of the world? Or is micro-irrigation mostly used for cash-crops only? Some elaboration on this in the manuscript is needed to justify the research setup and to put the results into perspective.

Response: We appreciate your valuable suggestion. Due to the high cost and technical requirements, micro irrigation applications are limited and are mostly applied to cash crops. However, there is a serious shortage of water resources in some croplands in China. And the spatial and temporal distribution of water and soil resources is uneven. Developing water-saving irrigation has become an important way to alleviate the prominent contradiction between water resources utilization and grain production in China. According to NBSC (2021), the area of water-saving irrigation projects in China in 2019 was 37 million ha, including 7 million ha for micro irrigation. Therefore, micro irrigation does apply to food crops in China despite the limited irrigated area. For instance, in Xinjiang province, the area of micro irrigated maize and wheat has been 0.033 million ha in 2009 (CIDDC, 2022), of which wheat area accounted for the main component, up to 0.031 million ha (Wang et al., 2011). Meanwhile, some scholars are conducting research on micro irrigated maize (Bai and Gao, 2021; Guo et al., 2021) and wheat (Li et al., 2021; Zain et al., 2021) in China, especially in the North.

4. What assumption do you take in terms of irrigation strategy/scheduling? This needs to be added to the methods. And how does this affect your results? This is important to address in the discussion, preferably with some quantitative substantiation. The more irrigation events you have, the more effect you will see from moving to a more efficient irrigation application technology (from furrow to drip). So I suppose your outcomes in terms of WFP for different irrigation technologies are quite sensitive to the assumption for the irrigation trigger (x% of soil moisture depletion?) and amount (back to field capacity?).

Response: We are very sorry for our unclear expression and deeply appreciate your valuable comment. We realized that description of different irrigation techniques settings was missing in Section 2.3 (original 2.2) Water footprint per unit crop calculation. Therefore, the following will be added at the end of Section 2.3. And the relevant table will be placed in the supplementary material.

“In the simulation, we considered different planting modes, namely rain-fed and three different irrigation techniques (furrow, micro, and sprinkler irrigation). The irrigation schedule of three irrigation techniques in model was Generation of Irrigation Schedule, namely the generation of an irrigation schedule by specifying a time and depth criterion for planning or evaluating a potential irrigation strategy. Table S6 shows the parameters of three irrigation techniques (Raes et al., 2017). We can adjust the simulated ET and Y according to the performance of the irrigation schedule.”

Table S6. Parameters of three irrigation techniques.

Irrigation technique	From day	Time criterion	Depth criterion	Water quality	Soil surface wetted
		Depleted RAW	Back to FC	Ecw	
		(%)	(+/- mm)	(dS m^{-1})	(%)
Furrow	1	50	10	1.5	80
Micro	1	20	10	0	40
Sprinkler	1	50	10	1.5	100

5. The most common abbreviation in water footprint assessment literature for water footprint is WF not WFP. I strongly suggest to stick to WF.

Response: Thank you very much for your valuable advice. We will change the abbreviation of water footprint in the manuscript to WF entirely.

Specific comments

6. The abstract should mention what method (model) has been used to estimate WFPs.

Response: Thank you very much for your suggestion. The following will be added to the abstract according to your suggestion.

"AquaCrop model with the outputs of six GCMs in Coupled Model Intercomparison Project Phase 5 (CMIP5) as its input data was used to simulate the WF of maize and wheat."

7. "Wheat WFP will increase under RCP2.6 (by 12 % until the 2080s), while decrease by 12 % under RCP8.5 until the 2080s." Please add a brief explanation for this opposite trend under RCP8.5 in the abstract.

Response: Thank you very much for your comment. The reason is that the CO_2 concentration in 2080s under RCP8.5 is higher, which leads to a higher increase in wheat yield and decrease in wheat WF. We will add this to the abstract.

8. Please add in the abstract what benchmarks have been determined. You mention that "Furthermore, the spatial distributions of WFP benchmarks will not change as dramatically as those of WFP" but the WFP benchmarks themselves have not been mentioned earlier in the abstract.

Response: Thank you very much for your suggestion. The following information will be added to the abstract according to your suggestion.

"WF benchmarks of maize and wheat in the humid zone are 13–32 % higher than those in the arid zone. The differences in WF benchmarks among various irrigation techniques are more significant in the arid zone, which can be as high as 57 percent, for WF benchmarks for the 20th production percentile of sprinkler-irrigated and micro-irrigated wheat in 2013. The changes in WF and its benchmarks will be similar in response to future climate change. Nevertheless, WF benchmarks will not change as dramatically as WF in the same area, especially the area with limited agricultural development."

9. "The present study demonstrated that … must be addressed and monitored". Stated too strongly. Did you really provide evidence that this must be done (in order to …)?

Response: We are very sorry for our unclear expression and use of incorrect word. We will modify L.25-L.28 in the abstract to the following content according to your suggestion.

"The present study demonstrated that the visible different responses to climate change in terms of crop water consumption, water use efficiency, and WF benchmarks under different irrigation techniques cannot be ignored."

10. A general overview of the methodological steps at the start of the section is missing. You now jump directly into "Determining the baseline year", but it is not yet clear that/why you need to determine that (and why you use the Aridity Index for that).

Response: We deeply appreciate your valuable comment. We will add the Section 2.1 Research set-up, which provides a general overview of the methodological steps, at the beginning of Section 2 Method and data. The content is as follows.

"2.1 Research set-up

We studied the spatiotemporal responses of blue and green WF and corresponding WF benchmarks for two crops (maize and wheat) to future climate change under two climate change scenarios (RCP2.6 and RCP8.5), four different planting modes (rain-fed and furrow-, micro-, and sprinkler-irrigated). Firstly, we need to determine the baseline year. Secondly, we consider different planting modes to quantify WF and corresponding WF benchmarks of two crops in the baseline year and future year levels under two climate change scenarios. Finally, the spatiotemporal responses of crop WF and corresponding WF benchmarks to future climate change are analyzed."

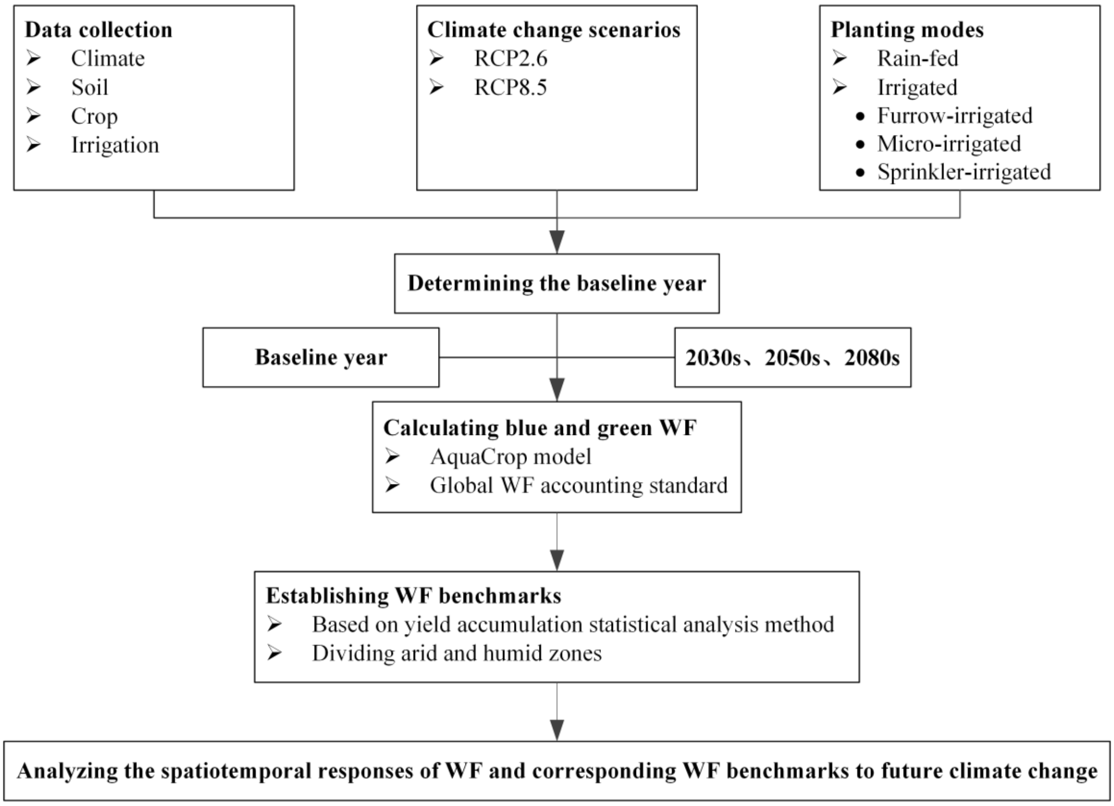

Figure 1. Flow chart for the study.

Meanwhile, the following will be added to Section 2.2 (original 2.1) Determining the baseline year according to your suggestion.

"To ensure that the simulation results of future climate change scenarios are still reliable and meaningful, we need to determine the baseline year. Climate determines the annual variability of WF (Zhuo et al., 2014). The baseline year should be determined when there is a relative balance between aridity and moist. Thence, the aridity index (AI) was used here."

11. Why do you take the maximum root depth (Zx) and Harvest Index (HI) from Allan et al. (1998)? These parameters are also available for maize and wheat

in the default crop files that come with AquaCrop, like the rest of the parameters that you take from Raes et al. (2017).

Response: We are very sorry for our unclear expression and use of incorrect word. The reference manual of AquaCrop (Raes et al., 2017) does have default maximum root depth (Zx) and Harvest Index (HI). Since AquaCrop model itself is developed by Food and Agriculture Organization of the United Nations (FAO). In order to make the model simulation more reliable, we reset the Zx according to the FAO-56 recommendation (Allan et al., 1998). In addition, we further combined the literature research on maize and wheat in China to reset the HI. In this way, we make the crop parameters more in line with the actual situation in China.

12. Refrain from mentioning that in your study the AquaCrop model was coupled with GCMs. You did not couple these models. You used GCM outputs as input for AquaCrop. That is something different than coupling models.

Response: We are very sorry for our unclear expression and deeply appreciate your valuable comment. We will modify L. 404 in Section 4 Conclusions to the following content according to your suggestion.

"AquaCrop model with the outputs of six GCMs in CMIP5 as its input data was used to simulate the WF of maize and wheat."

13. In the before last sentence of the conclusion you suddenly introduce other agricultural management practices that water-saving irrigation technology to reduce agricultural water use, such as mulching. The way it is phrased suggest that this is a conclusion from this study, which is not the case. Thus, you may want to rephrase this. Also, it is advised to add in the Introduction a description on the alternative options to reduce agricultural water use, after which you decide to focus this study on exploring the effects of water-saving irrigation technology only.

Response: Thank you very much for your valuable comment. We will delete the relevant inappropriate expression in Section 4 Conclusions according to your suggestion. Meanwhile, we will add the consideration to Section 3.5 Discussion on the choice of two WF benchmarking methods and different agricultural management practices in combination with your General comment 1. The content is as follows.

"Three are two methods of establishing WF benchmarks (Hoekstra, 2013). Method 1 is based on yield accumulation statistical analysis. Due to the variability of WFs found across regions and among producers within a region, for each crop, we can select the WF of 20 % or 25 % of the producers with the highest water productivity as the WF benchmark (Mekonnen and Hoekstra, 2014). Method 2 is based on the available optimal technique analysis. We can compare the WFs at each location under different agricultural management practices and take the WF associated with optimal practice, which results in the smallest WF, as the WF benchmark (Chukalla et al., 2015). Both methods establish WF benchmarks based on the maximum reasonable water consumption in each step of the product's supply chain (Hoekstra, 2014). Method 1 is suitable for large-scale application. The differences in environmental conditions (such as climate) and development conditions should be considered comprehensively (Mekonnen and Hoekstra, 2014; Zhuo et al., 2016a). The drawback of Method 1 is that no matter what spatial scope one takes in grouping producers, within that scope there will still be variability from place to place even if the differences in regional environmental and development conditions are taken into account (Schyns et al., 2022). Method 2 is suitable for smaller scale and overcomes this drawback of Method 1 to some extent. While the Method 2's drawback is that it has the higher requirements on the setting and simulation of different agricultural management practices. We mainly want to explore the response of large-scale WF to future climate change under specific irrigation technique, that is, each irrigation technique has its corresponding WF benchmarks. And only one agricultural management practice, that is irrigation, is considered here. Therefore, we choose Method 1. If conditions permit, we strongly recommend that Method 1 and Method 2 be combined when establishing small-scale WF benchmarks. We can consider different agricultural management practices, such as irrigation, mulching techniques and so on. They can be combined to further determine WF benchmarks."

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