Response to Reviewer #1

The objective of this manuscript was to estimate sectoral future water withdrawals under the recently developed shared socio-economic pathways (SSPs). Simplified models were developed to simulate future water withdrawals for the agricultural, industrial and municipal sectors. Historical and base year data from FAO built the basis of each model, i.e. the calculation of future municipal and industrial water withdrawals is based on historical trends. For the agricultural sector, the extent of area equipped for irrigation, crop intensity, and irrigation efficiency were estimated in a very simplistic way. This manuscript is a good one, a well-structured text that is clearly written.

Thank you.

Nevertheless, some changes need to be made in order to get the manuscript published. Two general remarks: first, the title says "water use" but the authors calculated only water withdrawals. The authors should make clear that water use and water withdrawal have the same meaning.

We would like to keep the title as is, including "water use". As you pointed out, we mainly estimated water withdrawal for industrial and municipal water, however, our model primarily calculates water consumption for irrigation water. Moreover, Part 1 only introduces the boundary conditions to estimate irrigation water withdrawal and consumption, not including results. Considering these points, we concluded that it is better to use the general term "water use" for the title of this paper. Please note that the term "water use" is defined in Introduction.

Second, the authors use agricultural sector but refer only to irrigation. Here, the authors should exchange "agricultural water withdrawals" by "irrigation water withdrawals" in the text. This may help to avoid confusion.

We agree with you that the term "agricultural water" in the draft paper only included irrigation water. We are going to change the term into irrigation water, and modified the whole text accordingly.

The authors may check other statistics next to FAO as for many countries (e.g. in Northern America, Europe) more measured data records are available. Historical data is also available from Shiklomanov and Rodda (2003).

Reviewer #1 recommended that we add datasets other than FAO AQUASTAT, particularly individual national statistics. We agree with you that it would enable us to add insightful analysis on historical change in water use mainly in developing countries. However, in this study, what we need is modeling applicable for developing countries without such good information. For this purpose, we believe FAO AQUASTAT is sufficient which is virtually the only dataset covering the almost all countries in the world. The discussion here will be added to text.

Unfortunately, there is no conclusion summarizing the main outcomes. I am sure the authors can do better. Some more specific comments are given in the following text

We are going to add discussion to Summary Section substantially, responding to the comments from reviewers. After revision, Summary Section will be largely substantiated.

1) Page 13880, line 17: The numbers for irrigated area are far too small.

There were typos. We will correct them into 2.7×10^6 km^2 and 4.5×10^6 km^2 respectively.

2) Page 13881, lines 11-16: The authors should clearly state that the climate scenarios and shared socio-economic pathways have been independently developed.

We will add this information.

3) Page 13881, lines 19-23: I do not agree with these statements. What is your basis for this statement? Water use scenarios have been associated with socio-economic scenarios, e.g. MA, GEO.

This part was a little bit overstated. We are going to revise it.

4) Page 13881, line 28: In order to assess local water scarcity, a higher spatial resolution would be required.

Here we mentioned only temporal resolution. We just wished to mention that the annual time interval is too coarse for water scarcity assessments. We are going to revise this part.

5) Page 13882, line 1: The novel global water scarcity assessment is not part of this manuscript. If *mentioned, please add few words about the novel.*

We will add and revise explanations. We believe our water scarcity assessment is novel in terms of two points. First, this assessment is one of the first example using the new scenarios (RCPs, CMIP5, SSPs). Second, it is the first example using CWD index, showing some advantages compared with a widely used WWR index. We acknowledge some other indices have been proposed other than CWD. We extensively discussed both the benefits and shortcomings of CWD.

6) Page 13882, line 4: Calculation of water withdrawals on a daily temporal resolution only valid for irrigation. Municipal and industrial water withdrawals are simulated annually.

The model abstracts water from the river at daily interval. We will keep this part as is.

7) Page 13882, lines 8-10: There are several scenario assessments available which could be used as guidelines, however, the model assumptions behind these assessments are seldom published.

We wished to mention here that the guidelines of SSPs are still lacking. We will revise this part.

8) Page 13882, line 11, 12: please exchange "report" by "manuscript"

We will change the term report into paper.

9) Page 13885, lines 1-2: This information is of importance, and thus needs more explanation.

We will add explanations how we set RCPs for Policy runs.

10) Page 13885, line 20: when omitting livestock, please use the wording irrigation instead of agricultural water withdrawal.

We are going to change the term throughout the text.

11) Page 13886, line 9: add Siebert et al. 2006

We will add this literature.

12) Page 13886, line 21: better "multiple cropping" instead "The planting of multiple crops"

We are going to correct it.

13) Page 13887, line 19: MA scenarios reference: MA scenarios differ widely as climate, socio-economics, agriculture, energy and water were simulated by different global models. E.g. simulations for estimating future agricultural land and irrigated areas were carried-out by IMAGE and IMPACT. IMPACT provided results for irrigated areas as well as irrigation efficiencies on FPU level. This modeling framework is probably not well documented. Page 13887, lines 26-29: Same as above.

Thank you for this useful information.

14) Page 13888, lines 4-6: I agree, still missing!

Thank you!

15) Page 13888, line 20: Voß et al. (2010) should be updated by Flörke et al. 2012 (in press)

We will add Flörke et al. 2012 (in press).

16) Page 13889, line 3: GDP per capita

We will correct it.

17) Page 13889, line 5: "similar to the" Needs some explanation, unclear what is meant.

We are going to revise this part.

18) Page 13889, lines 13-17: well, in this sense the whole future is unclear and uncertain.

We are going to modify this part. We wished to mention that it is not obvious whether it is the best approach to keep using the parameters that were observed in the 20th century throughout the 21st century."

19) Page 13889, lines 20-21: But different future conditions lead to different water use results although the modeling concept is the same for both due to the fact of different future assumptions. The problem here is the national breakdown of future projections and assumptions, not the modeling approach itself

We partly agree with you, but what we mentioned here was extremely simple. If the input data is same, a model produces the same outputs. We will revise this part to avoid potential confusion.

20) Page 13890, line 18: irrigate area increases everywhere, no decrease possible. Does the model distinguish between different crops to be irrigated? If so, what crops will be irrigated on the extended area?

We fixed the crop type at circa 2000, and assumed that the same crop was planted in both irrigated and rainfed cropland. We will add this information here because currently this is only explained in Part 2.

21) Page 13890, line 20: irrigation efficiency: Is there an efficiency threshold, i.e. to make sure that e becomes larger than e.g. 0.9 or 1? The latter could be possible in regions where efficiency is already high.

Currently there was no upper limit of irrigation efficiency, and it could be reach to 1 (no loss at all). We largely understand your concern what would be the possible upper bound of irrigation efficiency. We will add this discussion.

22) Page 13891, line 7: efficiencies from Döll and Siebert are rather old, better to use data from e.g Rohwer, J., Gerten, D., and Lucht, W.: Development of functional irrigation types for improved global crop modeling, PIK, Potsdam, Germany, PIK-Report 104, 2007.

Thank you for noticing this. We will try to use this data in the near future, but at least, our preliminary analysis suggested that the results were not substantially different between Döll and Siebert (2002) and Rohwer et al. (2007).

23) Page 13891, lines 8-9: Does each grid-cell belonging to a region or country get the same information?

Yes. We will add this information.

24) Page 13891, lines 13-14: MA goes beyond 2050, projections cover the whole 21st century.

Thank you. We will correct this.

25) Page 13892, line 12: industrial water withdrawals may be overestimated in countries where a huge part of electricity is produced by hydropower.

Thank you for pointing out this. We will add this in Section 6.5 (uncertainty in industrial water scenario).

26) Page 13892, line 16: only 16 countries to validate global model. This should be judged in the uncertainties' chapter.

Thank you. We will add discussion on this problem in Section 6.5 (uncertainty of industrial water scenario).

27) Page 13893, line 28: downscaling industrial water withdrawals with population data has its disadvantages.

We will mention some other approaches such as using night-light intensity and municipal area fraction.

28) Page 13894, lines 5-7: Not clear what is meant.

What we meant here is that both industrial and municipal water model are regression models commonly facing at severe limitation of data availability. We will revise this part for clarity.

29) Page 13894, line 10: 20 years time series but only 3 to 6 data points. This should be mentioned.

We will add this information here.

30) Page 13894, lines 24-25: there are several studies available giving an opposite answer as household (domestic, municipal) water use is not only price elastic but also income elastic (Zhou *and Tol 2005, Dalhuis_et_al_2003).*

Thank you for introducing interesting literatures. What we wished to mention here is there seems no general rules and trends applicable globally linking national per capita GDP and national municipal water use. We will revise this part for further clarity.

31) Page 13897, line 7: How is environmental consciousness set for SSP4?

SSP4 depicts the world that divided into rich and poor, but it doesn't directly mention environmental consciousness for both sides. Because the adaptation challenge of SSP4 is large, we interpreted that the water efficiencies in developing countries wouldn't improve much and their water use intensity would kept high. We will add this discussion because it is not clearly mentioned in the current text. We believe further detailed information on SSP4 will be provided by the developers of SSPs

32) Page 13898: agricultural (irrigation) water withdrawals are not shown in graphs and maps.

Because irrigation water consumption and withdrawal are estimated and discussed in Part 2, there are no graphs or maps in Part 1.

33) Page 13901, lines 12-13: replace Voß et al. (2011) by Flörke et al. 2012 (in press). Some text about model uncertainty may already been mentioned in the text describing the models.

We will add Flörke et al. 2012 (in press). We will further revise this section to exclude redundancy.

34) What are the main conclusions? The summary does not provide the main conclusions or outcomes from this study.

We are going to add conclusions and main outcomes of this study.

35) Table 1: The problem of SSP5: it's true that technological development is high and it is also true that environmental consciousness is low. But the interpretation regarding estimating future water withdrawals is questionable. I think that SSP5 high technology leads to getting each drop of water (resources) but not saving water. If efficiency is high, future will not become water intensive! That is a contradiction.

SSP5 depicts the world relying on fossil fuels, but it doesn’t mention the other resources in detail. Because the adaptation challenge of SSP5 is small, we interpreted that the other natural resources including water are less intensively used. We will add this discussion. We believe further detailed information on SSP5 will be provided by the developers of SSPs.

36) Table 2: Irrigation efficiency has increased under MA, TG scenario (differentiation between 19 regions).

Thank you. We will correct this.

37) Table 3: Revise Voß et al. (2010): Driver is: thermal electricity production

Thank you. We will correct this.

38) Table 4: Revise Voß et al. (2009): Driver: population and GPD per capita, technological change (parameter), structural change (parameter)

Thank you. We will correct this.

39) Table 7: caption does not explain the content

Sorry, we couldn’t find any problems in the caption.

40) Table 9: HE for SSP5 is questionable. (see comment to table 1)

Please See reply to 35)

41) Figure 1a: please cf to O’Neill et al. 2012 (similarity between figures is too high)

Thank you. We will add this.

42) Figures 4 and 5: few number of data points.

We will mention this problem in body.

43) Figure 4: Does India use 0 water in the industry sector in 2000? Approach is based on few measured data, although many more exist from other statistics, e.g. Japan.

You are right; Inida is erroneous because we fixed the industrial water use intensity throughout the period. About the data used, please see our reply to General Comments.

44) Figure 5: same as for Figure 4. The figures shown do not really represent the "typical" industry nations, e.g. USA, Germany, France, also Brazil as an emerging country.

Yes, we agree with you, but in order to cover the whole globe, “not-typical” industry nations must be modeled as well. We completely agree with you that we should add data as much as possible, but still the difficulty largely remains how to model industrial water in particularly least developing countries, and how to project their future water demand.

45) Figures 7 and 8: few number of data points.

We will mention this shortcoming in Setion 4.3.

Response to Reviewer #2

The paper presented by Hanasaki et al. concerns the first part of a two-part paper. I have read this manuscript with interest. The paper is overall well-written. However, I do have some major concerns regarding how the paper is structured in relation to the second part of a two-part paper, as well as minor comments.

Thank you.

1. Abstract: "...the irrigation area in 2085 varies between 270 and 450 km2,..." Is the unit correct?

There were typos in Abstract. We will correct them into $2.7\times10^6 km^2$ and $4.5\times10^6 km^2$ respectively.

2. Abstract: "the irrigation area in 2085 varies between 270 and 450 km2, industrial water between 246 and 1714 km3 yr-1, and domestic water withdrawal between 573 and 1280 km3 yr-1." How about describing irrigation water withdrawal, rather than irrigated areas here, consistent with industrial and domestic water withdrawal?

Estimation of irrigation water consumption/withdrawal is reported in the accompanying paper (Part 2). Therefore, only irrigated area is shown which is developed in this paper (Part 1). Please note that this is one of the key factors in estimation of the future irrigation water use.

3. Abstract: "The water use scenarios can be used for global water scarcity assessments by identifying the regions vulnerable to water scarcity and analyzing the timing and magnitude of scarcity conditions." I would change to "The water use scenarios can be used for global water scarcity assessments by identifying the regions vulnerable to increased water use and analyzing the timing and magnitude of scarcity conditions."

Thank you. We will revise this part consulting English Editor.

4. Page 13882,: "The study is presented in two-part papers."?

We will correct this.

5. As far as I understand, the paper concerns modeling water withdrawal (although the title indicates water use) only, and there is no model development for water consumption. Please clarify this point and revise where appropriate.

As Reviewer #1 pointed out, we mainly estimated water withdrawal for industrial and municipal sectors. We will emphasize this in Introduction and Methods sections.

6. For Section 2, I would suggest the authors to shorten further about the narrative scenarios well documented by O'Neill et al. (2012), and to focus more on how your water use scenarios correspond to which SSP and RCP scenario.

We will remove the description on SSP which is not directly relevant to our water use scenarios as much as possible.

7. "Higher values indicate socio-economic factors that would make it more difficult to reduce emissions." "Higher values indicate socio-economic factors that would make adaptation more difficult." Not very clear, please rephrase.

We will revise these parts for further clarity. Actually, these sentences just explain the axes of Figure 1a.

8. I do not really see the necessity or justification including literature review (Section 3) about sectoral water withdrawal. These information are well-presented in previous literature. This section should be omitted or considerably shortened. The paper should focus on novel aspects of development of water use scenarios presented in Section 4.

The models we finally adopted are relatively simple ones. We needed to select simple ones because of strong limitation in availability of input and validation data. One of the most important points of this study is to balance model complexity and data availability, and literature review is indispensable to justify our model selection. We are going to remove literature reviews less relevant to this study, but substantial amount will be remained.

9. Section 4 should also be shortened and focus on new aspects of model development.

We will remove the contents of less relevant as much as possible.

10. Irrigated areas expand within the grid cell, or over the present extent of irrigated areas (area equipped for irrigation) only (no horizontal expansion). Is this a good assumption considering available land within the grid cell and other land use types, e.g. urban area, rainfed crop area, natural vegetation? And, is livestock water withdrawal included? If not, please change agricultural to irrigation water withdrawal. Regarding the paper 2, rice is irrigated during 100% of the cropping period. Farmers generally stop irrigating rice a few weeks before the harvest (late development stage). If you irrigate rice (25% of all irrigated areas) during all cropping period, your irrigation water demand for rice is likely overestimated.

In this study, irrigated area was increased within the grid cells. As you pointed out, grid cells includes urban areas, natural vegetations, and others, and it needs careful discussion whether they can be converted into new irrigated croplands. However, it is beyond the scope of this paper to seek possible places to develop a new irrigation project in the world. The term agricultural water withdrawal will be replaced with irrigation water withdrawal. We are going to add this discussion in Section 4 (model development). We will also add discussion that the irrigation period could be too long due to modeling assumption which potentially leads to overestimation in irrigation water demand.

11. "To make the results grid-based, we assumed that industrial water withdrawal is geographically distributed proportionally to the population." This means that industrial water withdrawal has a very similar distribution with domestic water withdrawal which is based on population data. In general, industrial activities are concentrated near urban areas. Including rural population when downscaling industrial water withdrawals will likely make mismatches in the gridded industrial water withdrawal. I would suggest to use gridded urban population maps or night-time light intensity to distribute industrial water withdrawals over the grids.

We are going to mention some of the earlier studies that used night-time light and urban area to distribute industrial water withdrawal. Please note that the current spatial resolution is approximately 50km × 50km, which barely resolves the largest cities in the world. We speculate that there would be no significant difference for this resolution in either method.

12. Which data is used to geographically distribute domestic water withdrawals to a grid scale? Population data from CIESIN?

We used the population data of CIESIN to spatially distribute the municipal water. We will revise this part for further clarity.

13. In Section 6, after presenting water withdrawal scenarios, there are long descriptions about the uncertainty and comparisons with earlier studies for each water withdrawal sector. These descriptions make difficult to read the results presented in the paper. 'Comparisons with earlier studies' and 'Uncertainties in' should be substantially shortened and should be possibly discussed all sectors together in a more concise manner.

> We will re-consider the structure of Section 6. Particularly, we will try to shorten Section 6 as much as possible.

14. This type of extrapolation of future water withdrawals suffers from the weakness that expansion of irrigated areas and increase in water use intensity only occur over the present irrigated area or population extent, thus not horizontal expansion (no irrigated areas are developed if no irrigated areas exit at the present (Siebert et al., 2005). Within the country or region variations remain the same. This also substantially affects the results of global water scarcity assessments. The authors should at least discuss this limitation that comes from the series of assumption used in this study

> Thank you for good suggestion. We are going to mention that irrigated area only increases where irrigated area already exists in Section 6.2 (uncertainties of agricultural water scenarios). We will also mention the consequences of this assumption.

15. All-in-all, the authors did a good job and presented an interesting work. However, I think the paper will be much stronger when the assessments presented in a two-part paper are combined and presented in one paper. This paper (part 1) can be significantly shortened omitting those sections describing literature review. The new aspects presented in the paper 1 can be inserted into the companion paper (part 2), making one combined paper. In this way, the newly developed water use scenarios based on the SSPs can be presented with water scarcity assessment in a much more coherent manner. The impact of socio-economic development incorporated in water use scenarios can be easily recognized in resulting water scarcity. Since this paper focuses on global water scarcity assessment under the SSPs, joining a two-part paper into one paper combining the development of water use scenarios under the SSPs and the assessment of water scarcity seems to be a logical choice. The authors can use supplement if the paper requires additional spaces.

> The suggestion of Reviewer #2 is to combine Part 1 and Part 2, and a similar one is raised by Reviewer #4 of Part 2. This is a good option, but due to the reasons shown in the first item of Reply to Reviewer #4 of Part 2, we believe double-featured paper would be the

best. As shown above, we are going to revise the whole draft to make as concise as possible, and as logical as possible.

Fig. 2: The axis legends are unclear

Thank you. We will fix this.