

# 1 Reply to Reviewer # 1

We wish to thank the reviewer for this positive review and the important comments to improve the paper.

1. Page 4699: *A schematic of the approach would be useful.*

Thank you for the suggestion, we have added such a schematic overview.

2. Page 4700 lines 9 to 11. *This is awkward phrasing the word account is used in two different senses in the sentence. See also line 26.* 3. Page 4701 line 2. *Detailed analyses of what?*

Thank you, we have rephrased both paragraphs:

- 'accounts' has been replaced by estimations where applicable

- The most detailed analyses *of generic, sectoral water requirements*[...].

4. Page 4702 line 8. *I suggest referencing: Michelle T. H. van Vliet et al. Vulnerability of US and European electricity supply to climate change, Nature Climate Change, 2, 676681 (2012)*

Thank you for the suggestion, we have added the reference.

5. Page 4707 section 2.3.2. *I would like to see some more detail and context on the climate change and population scenarios used for example how does the rainfall change in the two regions?*

We have added a paragraph, briefly discussing the magnitude and direction of projected changes in each variable. We have also prepared additional Supplementary Material, providing tables of the region-specific values of all analysis steps.

6. Page 4714 lines 13 and on. *How good is the data from other regions is there a recommendation on collecting better information?*

We have extended this paragraph in the discussion, clarifying that we rely comparable data for both regions. A more detailed, local analysis would certainly be important in a future analysis, potentially collecting data specific to the analysis.

7. Page 4714 lines 21 and following. *How would we verify these results are they realistic?*

It is not completely clear to us how this corresponds to the indicated section, as the paragraph summarizes findings from other studies to support our results. The paragraph mentioned in the previous comment also implicitly addresses the topic of verification in the revised manuscript. Specifically, the paragraph discusses the importance of including more locally-specific information to refine the approach in order provide more detailed results to inform water management.

## 1 Reply to Reviewer # 2

We wish to thank the reviewer for several important points, which will improve the discussion and presentation of our results.

*General comment: The approach to assess the water adequacy from the viewpoints of not only water availability but also water access and quality is valuable for an improvement of water security and sustainable development. They broadly present the fuzzy logic approach clearly. However, they don't necessarily provide conclusions for their objectives in the case studies. For instance, they don't explicitly show the impacts on the water adequacy due to population growth in the future, although they state that we further assess the impacts of climate change and population growth on the adequacy of water resources. Furthermore, the conclusions for limits and constraints under climate change is unclear. In summary, I find this manuscript suitable for publication after revisions to make clear the conclusions for these objectives.*

We have revised the results, discussion and conclusions sections in order to clarify our conclusions with regard to both of these aspects.

In the initial version, we already briefly take up the aspect of impacts of population growth on water availability at several points in the results and discussion section. We have extended these parts in the revised manuscript, to more clearly reflect the results in this regard. We have also adjusted the phrase in the abstract to make clear, that we do not separate the impacts of climate and population. The sentence now reads: "we further assess the impacts of climate change in combination with population growth on the adequacy of water resources."

We also propose to rephrase the title slightly. We suggest to reduce the emphasis on climate change, by taking the term itself out of the title. As the results show, the impacts of population change are more important in short-term future scenario than climate change. We have also extended this aspect in the discussion of limits and constraints, making clearer within the manuscript that in the assessed timeframe, impacts of climate change are less important than population growth in the short-term future scenario.

*Specific comment: P4699, L17-18; Is a higher development status more associated with economic growth and improvement of infrastructures (including water infrastructure) rather than increasing per capita water use?*

We have rephrased this sentence to: "A higher development status usually results in increasing per capita water use, due to increasing water consumption across sectors."

*P4704, L19; I recommend you to show the year for water quality (Vrsmarty et al. 2010a,b) to clarify the suitability of the data for this study as current and future water quality.*

Thank you for this comment, we have adjusted this in the manuscript.

*P4707, L20-21; How do you distribute the water availability to the three sectors? How do you take into account cascading water?*

For the sectoral adequacy assessment, it is assumed that all of the available water resource can be used by the respective sector. For the assessment of the overall adequacy, cumulative water needs of all sectors are taken into account. We have clarified this in the manuscript.

We are not completely certain, what the reviewer refers to with regard to 'cascading water'. If this refers to the re-use of water between sectors, then we do not take this into account, as we look at yearly averages of availability and requirements. Accounting for water re-use would require a more process-based model. We have added this as a highly relevant point within the discussion section.

*P4708, L8; The description in the text, current conditions of water availability (HAD-base), is not consistent with the caption in Figure 2, availability data from the GFDL-ESM2M model under current (GDFLbase).*

Thank you, we have adjusted this in the text.

# 1 Reply to Reviewer # 3

We wish to thank the reviewer the several comments, which will improve the conciseness and clarity of the presentation of our method and add some important aspects to the discussion.

*The biggest concern is that some variables are allowed to change overtime (e.g., water availability), while others (e.g., water demands, etc.) are held constant to what was estimated in the literature (e.g., Vorosmarty et al 2010a,b, ICF 2013, Smakhtin 2004, Howard and Bartram 2003). Ideally all variables/indicators should be allowed to evolve temporally following the two RCP scenarios. For example, water demands are likely to increase and using a range from the literature is not sufficient especially that there are numerous models that generate those following the RCP scenarios. The WaterGAP, GCAM, WBMplus, H08 are a few of those models. When the modeling capability is lacking, this needs to be stated clearly.*

We agree, that it would be preferable to include projections of all variables in the calculation. However, to our knowledge at present projections of the variables included in the analysis, other than water availability as well as populations projections, are not available.

For our assessment, we have focussed on addressing water requirements, rather than water use or water withdrawals. To our knowledge, the models the reviewer refers to assess the current and future development of water use and water withdrawal, but do not actually reflect on how this relates to the requirements of different sectors. If less water is used in a region, this may also be due to limitations in access or availability. Certainly, more detailed assessments of regional to local water requirements would be advisable, to account for local water needs in more detail and also assess potential future requirements, however this outside the scope of the assessment.

We have revised several aspects of the manuscript:

- the paragraph on water requirements now more explicitly refers to the distinction between water use and water requirements, discussing why we chose to represent water requirements rather than water use/withdrawal
- we also discuss the raised points and the consequent limitations to the approach in more detail in the discussion section

*There are several questions that pertain to how the authors handled water availability. For example, how is water availability defined in this study? Is it runoff or streamflow, or something else? How does the paper distinguish between internally renewable water vs the inflows that come from upstream basins? Also the seasonality of water availability and demands are missing from the analysis, e.g., rain may occur during the non-growing season. why not compare the agricultural water demand to water availability during the growing season instead of the entire year?*

We have extended the respective paragraph to more precisely state the definition of water availability for the study. Briefly, water availability refers to the mean annual internal renewable water resource (blue water) and is represented by total runoff (surface and subsurface).

With regard to the question of including seasonality: the current aims at showing how water needs of different sectors can be accounted for and provides a first implementation of the approach. More detailed assessments of sector-specific needs would be interesting, but would require further adjustments of the method to a specific regional setting, which is outside the scope of the present implementation. We now discuss this point more specifically in the discussion section.

*There needs to be a more elaborative explanation of the various indicators that are used in the fuzzy logic step. Simply citing a paper to get the variables is not sufficient. I would suggest to at least describe how these indicators were computed in an appendix or supplemental materials.*

We have restructured and extended Section 2.3.1, which provides details on all indicators and their preparation, in order to ensure that the data preparation becomes clearer. To this end, we have also added more specific references to Table 1 throughout the Section.

*I am less familiar with the Fuzzy Logic theory, but the results seem to be very much sensitive to the weights assigned to the various indicators. The paper is full of subjective assumptions of what weight factor is used (0,0.2,0.4,0.5,0.6,0.8,1.0) and it is not clear how sensitive the results are to those assumptions.*

The reviewer raises a very important point here. Assumptions underlie the definitions of each specific values within the framework, including the thresholds to define membership, fuzzy operators, the values of gamma or the chosen input data. The choice of these values is clearly important, as they determine the final result.

One of the main advantages of fuzzy logic is the possibility to account for vagueness, which is associated with the system of analysis, while nonetheless allowing for a quantification. We choose to assess range of adequacy, which allow to account for a gradual assessment of conditions, allowing for vagueness and uncertainties associated with strict thresholds. Every exact number used in the framework is therefore uncertain. However, the order of magnitude and direction of each value is motivated through the context and properties of the variables. A full sensitivity analysis for the whole assessment framework is beyond what can be done within this publication, since a large number of factors will have to be checked for sensitivity and presenting the resulting complex information is rather topic of an entire publication. However, we tested the impact of our assumptions on the final result. The attached figure (Fig.1) exemplifies for the municipal sector, how results change with a variation of gamma at +/- 0.2.

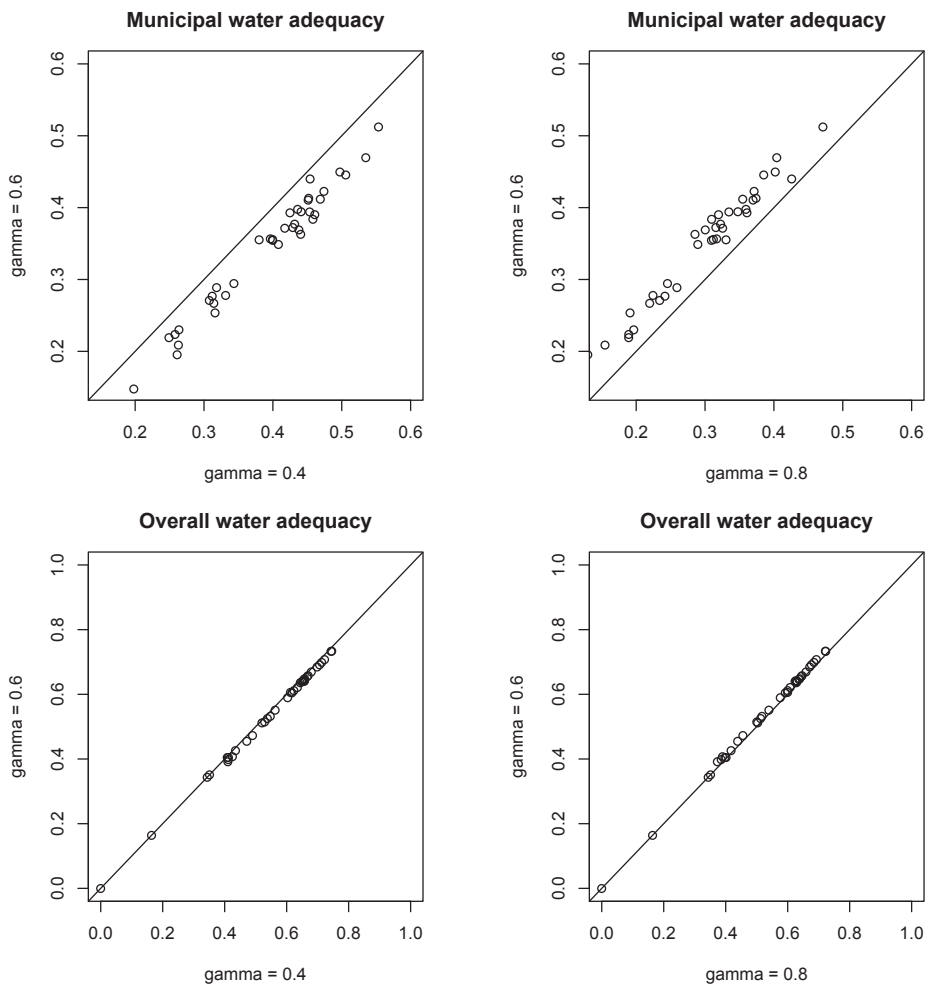


Figure 1: Comparison of results of municipal water adequacy (upper panels) and overall water adequacy (lower panels) with variations of +/- 0.2 of gamma-values for the aggregation of municipal water adequacy.