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Hydrology and Earth System Sciences
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Discussions

Interactive comment on "Assessment of potential implications of agricultural irrigation policy on surface water scarcity in Brazil" *by* Sebastian Multsch et al.

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Dear Referee #1,

we were much appreciate your thourough review of our manuscript. We provide our answers to your queries below.

Kind regards, all authors

Queries by anonymous referee #1 RC1 & answers by authors

Referee #1: The actual water withdrawals in each catchment are assumed to be twice the estimated crop water requirements.

Printer-friendly version

Discussion paper

Authors: Please note that the factor of two was applied to adjust the scarcity levels, because the original levels were related to gross water consumption. No such factor has been applied to the crop water requirements (equation 4). Water scarcity is calculated on the basis of water availability in the catchments and blue water consumption (equation 2). A detailed description can be found in the manuscript (page 7, 203-209):

In this paper, net water withdrawal (or blue water consumption) rather than gross water withdrawal is compared to water availability, often termed consumption-to-availability ratio (Vanham et al., 2018). Therefore, the scarcity levels described above were adjusted to reflect that withdrawals also include non-consumptive losses at field scale and losses during transport of water to the field, which are not considered when calculating blue water consumption. To account for this a factor of 2 was applied, which is a central estimate of the ratio between withdrawal and consumptive blue water use reported in Wriedt et al. (2008). The resulting scarcity levels represent the same classes of water scarcity from acceptable to very critical, but are adapted to the threshold values of 2.5, 5, 10 and 20%.

Referee #1: Historical time series (1980–2013) of meteorological data were used in the simulations, while it is not specified whether Q95 values were computed over the same time period.

Authors: Please note that we did not study the time period 1980-2013. Solely the year 2012 has been studied on purpose, i.e. the year before the policy under investigation (Law 12,787) came into effect in 2013 (stated on page 3, line 81. The calculation of the crop water balance, green and blue water consumption and water scarcity (relating water availability, i.e. Q95, to water consumption) has been carried out for the year 2012. Q95 is provided as an average over the years 2008 to 2016 by the ANA Geonetwork (http://metadados.ana.gov.br/geonetwork/srv/pt/main.home). The text has been modified in order to clarify the basis of Q95 (page 7, lines 194-195):

Again, please note that ANA provides the Q95 values as averages over the time period

2008 to 2016. The study year 2012 is at the centre of this average.

Note that the study year and the reasons for this choice are explained at the beginning of the manuscript (page 3, lines 80-81):

In addressing this issue, we restrict the analysis to irrigation expansion on cropping areas in 2012, representing the situation just before law 12,787 came into effect in 2013.

Referee #1: The analysis presented in the paper is interesting, but the discussion of the assumptions that are made in the study and of how they may impact on the results obtained is insufficient.

Authors: Please note that we have expanded the discussion to provide explanations regarding the assumptions made, together with their implications. Those additions are provided in various sections below, so we do not repeat all of those additions here. We simply do not want to duplicate the text here. We hope that this is acceptable.

Referee #1: The study area is very large and covers a variety of hydrological conditions. It can be expected that the shape of Flow Duration Curves will be quite variable among the different catchments and hence Q95 will represent very different fractions of the total water availability depending on the location. Reasons for using (only) Q95 as a water availability index must be discussed.

Authors: Q95 has been used as water availability index to comply with the definitions by the Brazilian water authorities (page 7, Lines 198-202), i.e. the authors want to make this work as useful as possible in practice by using the same indicators and definitions as those that are used in practice in Brazil:

Using the Q95 indicator for water availability, Brazilian water authorities consider the appropriateness of the water withdrawal, as a fraction of water availability (i.e. scarcity levels), to be acceptable when it remains below 5%, comfortable between 5 and 10%, worrying between 10 and 20%, critical between 20 and 40% and very critical above

40% (ANA, 2015). This classification is inspired by threshold values for water exploitation suggested by Raskin et al. (1997), and also used by the United Nations (UN, 1997).

Authors: The discussion section has been extended in order to elaborate on the selection of Q95 (page 12, lines 366-369):

With respect to the choice of a water availability indicator Q95 has been selected in order to provide a conservative water availability scenario. This is important due to the high variability of hydrological conditions in Brazil and to account for dry periods over time. Moreover, choosing Q95 complies with the indices utilised by the Brazilian Water Agency and decision makers.

Authors: Please also note that Q95 has been used in a spatially differentiated manner (i.e. for each catchment studied), as provided by the Geonetwork of ANA.

Referee #1: Q95 values that were used in the study refer to natural flows or to flows that are possibly modified by diversions occurring upstream? Which time period is covered by the timeseries used to estimate Q95 values? Timeseries were available for all the 166,842 catchments?

Authors: Q95 data were available for all catchments and calculated on the basis of the years 2008-2016 as provided in the publicly available data by the Geonetwork of ANA (http://metadados.ana.gov.br/geonetwork/srv/pt/main.home) (see comment above as well).

Referee #1: Length of the growing periods and Kc values of a given crop may vary in space and in time, mainly according to meteorological conditions. In the study constant values of these parameters were assumed. Given the extension of the area and the variety of conditions, I wonder if any attempt to assess the impact of this assumption on the estimated crop water requirements has been made.

Authors: Given that reliable region-specific data were available we acknowledge that further spatial differentiation of input parameters can potentially lead to an improvement of the accuracy of the results in large-scale studies. Here we have opted for an approach chosen by other global or nation-wide assessments of this kind (e.g. Mekonnen et al. 2011; Hoekstra et al., 2012 Hoekstra and Mekonnen, 2012; Multsch et al., 2017), whereby we used Allen et al. (1998) as our source for crop growth coefficients and supplemented these by data taken from a Brazilian study (Hernandez et al., 2014). We pair those data with spatially differentiated information on planting and harvesting dates, as provided by Companhia National de Abastecimento (Conab) (https://www.conab.gov.br/). We also would like to note that it was found (Multsch et al., 2013) that the choice of the PET calculation method will alter the results more significantly than potential adjustments of crop coefficients, should local data be available. We have added the following information to the discussion (p. 12, lines 370-379):

The selection of crop-specific parameter sets was an important aspect in the design of this study. Crop coefficients and length of growing seasons of the individual crops studied here have been assembled from a well-recognised source (Allen et al., 1998, i.e. parameters implemented in the FAO CROPWAT model), a Brazilian study (Hernandes et al., 2014) and regional information for Brazil, as provided by Companhia National de Abastecimento (Conab) (https://www.conab.gov.br/). We acknowledge that further spatial differention is desirable, should reliable data be available. We have chosen the procedures put forth by Allen et al. (1998), as their high level of robustness, transferability and repeatabilty have been shown (Pereira et al., 2015). Moreover, in a large-scale irrigation requirement study for the Murray-Darling basin, Multsch et al. (2013) report that the choice of the potential evapotranspiration calculation method outweighs the role of the local refinement of crop coefficients. Lastly, the region-specific crop calendars (Conab, 2015) were utilised for the determination of crop water requirements to account for varying conditions in different parts of Brazil.

Referee #1:Conveyance and distribution losses are assumed to account for 50% of irrigation water withdrawals. Part of this losses will be recirculated within the river systems, mostly through the groundwater, from upstream areas to downstream ones, with losses in upstream areas that might contribute to discharge in downstream river stretches. This is not considered at all in the paper and it might produce an overestimation of the impacts of irrigation water diversions, particularly in those catchments where the rivers gain flow from groundwater. This issue needs to be discussed.

Authors: We note that in this work blue water consumption was presented, which does not include conveyance or distribution losses. Confusion may have arisen due to the following: A factor of two was applied to adapt the water scarcity levels for this study (i.e. without conveyance and distribution losses) to those given by ANA, which are provided increased by regulated flow from reservoirs. We base this on Wriedt et al. (2008). Thus, the quantities of blue water calculated in the present paper are actually removed from the system by evaporation and transpiration. We acknowledge that evapotranspiration fluxes may return to a given system as precipitation (e.g. Berger et al., 2014). This is process is less important in our study, as we have subdivided the study area into 166,842 sub-catchments, i.e. we have subdivided the large-scale system where 'evapotranspiration recycling' may be important to consider into smaller sub-units. An explanation of this issue has been added to the discussion (p. 13, lines 379-383):

An important aspect when assessing water scarcity caused by agricultural water consumption are return flows, e.g. due to evapotranspiration recycling (Berger et al., 2014) or water losses in irrigation systems (Pereira et al., 2002; Jägermeyr et al., 2015). We neglect evapotranspiration recycling effects in the present study, since great care has been taken to subdivide the study area into sub-catchments with sizes where this effect does not play a significant role. The calculated blue water consumption represents net water requirements, which only includes evapotranspiration by crops and from soils.

Referee #1:I am not at ease with the way in which the term Water Scarcity is used in the paper: it sounds awkward to me to read that Water Scarcity is Excellent, even more so because this happens when the withdrawals are small compared to river flows, i.e.

when water availability is excellent. I would prefer using Use-to-Resource ratio (as in Raskin et al. 1997, that the authors mention), or something similar, rather than Water Scarcity here.

Authors: The definition of water scarcity has been chosen with a clear purpose in mind: to make this work as useful for decision makers in Brazil as possible. The definition has been adopted from the work by ANA, so that decision makers in Brazil can readily utilise the results of this study. Nevertheless, we agree that the term ‘excellent scarcity’ may need revision since an excellent level of scarcity seems unreasonable. For this reason, we modified the terminology of the classification, both in the text and in the relevant figures, i.e. ‘excellent’ has been replaced with ‘acceptable’ throughout.

âĂČ Supplement Referee #1 (p. 1, l. 22): I recommend to avoid using decimals: the accuracy of the estimates does not support it for sure

Authors: Thank you. This has been changed accordingly wherever it was sensible, and in particular in the abstract and the conclusions.

Referee #1 (p. 1, l. 31): two objectives are indicated: expansion of irrigated land and increase of productivity

Authors: Thank you. This has been changed accordingly, i.e. “one” has been replaced with “two”.

Referee #1: (p. 3, l. 7): this sentence is not clear, please revise

Authors: Thank you. This has been changed accordingly. The adjusted sentence reads: “The Brazilian national water agency ANA (Agência Nacional de Águas) uses blue surface water availability in operational management, whereby the river discharge, partly delivered by regulated reservoir flows, is compared to water withdrawals.” (p. 3, lines 72-74)

Referee #1 (p. 3, l. 8): provide here the definition that you adopt for "water scarcity"

Authors: Thank you. The definition used by us is provided in section 3.2 ('Blue water scarcity')). On p. 3, 1. 8 we describe other work and we would like to leave the flow of the text this way, i.e. we do not all of a sudden want to introduce a jump in the development.

Referee #1 (p. 3, l. 31): What do you mean by derived? Which data? Were these data available for each of the 166,842 catchments? For which time period?

Authors: Thank you. We have replaced the word "derived" with "obtained". Note that we have moved this sentence to the "Data" section (now section 2), as it does in fact belong to that very section. Yes, those data were available for 166,842 catchments. The study year is 2012, and the reason for doing so is stated in the manuscript (p. 3, line 80).

Referee #1 (p. 4, l. 9): which grid?

Authors: Thank you. We have moved the "Data" section (formerly section 3) forward in the text, so that it is now section 2, which will in our view help to clarify matters. Climate and soils data were available at grid-levels (see e.g. Table 1). Climate data at 0.25° x 0.25° and soils data at 1km x 1km (see Table 1). These are the grids that we refer to. We have also adjusted the text. But we would also like to point out that this is explained in both the "Methods" section and the "Data" section, however, now in an improved manner.

Referee #1 (p. 4, l. 13): indicate here the variable names used for green and blue water

Authors: Thank you. We have done so.

Referee #1 (p. 5, l. 2): the length of the phenological phases may change from one year to the other according to meteorological conditions and other factors. Can this variability be considered not influential?

Authors: Thank you. This is indeed an important aspect for a study that spans multiple years. However, please note that we have considered one year in this work (2012). We have provided a reason for this choice (see our earlier response). We have used the best data available at per sub-region of the country regarding the sowing and harvest dates (Conab, 2015). Hence, we argue that our approach is sensible.

Referee #1 (p. 5, l. 26): check spelling

Authors: Thank you. We have replaced “rained” with “rainfed”.

Referee #1 (p. 5, l. 28): idem

Authors: Thank you. We have replaced “rained” with “rainfed”.

Referee #1 (p. 6, l. 5): explain how the reservoir effect is taken into account

Authors: Note that we are using Q95 data provided by ANA, i.e. we are not adjusting the data set. The explanation provided is the explanation provided by ANA on their Geonetwork server (http://metadados.ana.gov.br/geonetwork/srv/pt/metadata.show?id=307).

Referee #1 (p. 6, l. 10): the hydrological regimes of the brasilian catchments are highly variable, therefore Q95 represents very different fractions of the total water availability. The reasons for using (only) this indicator should be discussed

Authors: Please note that Referee#1 has made this comment above and we have answered it. We therefore do not repeat our answer here.

Referee #1 (p. 6, l. 14): Raskin et al. index is based on average annual water resource flows and is called Use-to-Resource ratio. I do not think that calling it Water Scarcity index is a good idea: "excellent water scarcity" sound awkward to me

Authors: The definition of water scarcity has been chosen with a clear purpose in mind: to make this work as useful for decision makers in Brazil as possible. The definition has been adopted from the work by ANA, so that decision makers in Brazil can readily utilise the results of this study. Nevertheless, we agree that the term ‘excellent scarcity’ may need revision since an excellent level of scarcity seems unreasonable. For this reason, we modified the terminology of the classification, both in the text and in the relevant figures, i.e. 'excellent' has been replaced with 'acceptable' throughout.

Referee #1 (p. 6, l. 18): This assumption si crucial, as this ratio may be highly variable depending on the characteristics of the irrigation systems and of the catchments. A discussion of the situation in the areas that are now irrigated and of the assumptions that are made for the areas of irrigation expansions should be provided

Authors: Thank you. We have discussed this point above where this point had been raised as well (we note above what has been changed in the text to avoid confusion). A factor of two was applied to adapt the water scarcity levels for this study (i.e. without conveyance and distribution losses) to those given by ANA, which are provided increased by regulated flow from reservoirs. We base this on Wriedt et al. (2008). Thus, the quantities of blue water calculated in the present paper are actually removed from the system by evaporation and transpiration. We acknowledge that evapotranspiration fluxes may return to a given system as precipitation (e.g. Berger et al., 2014). This is process is less important in our study, as we have subdivided the study area into 166,842 sub-catchments, i.e. we have subdivided the large-scale system where 'evapotranspiration recycling' may be important to consider into smaller sub-units. An explanation of this issue has been added to the discussion (p. 13, lines 380-384)

Referee #1 (p. 6, l. 21): Conveyance and distribution losses account for 50% of water withdrawals, according to the authors' assumption. Part of this losses will be recirculated within the river systems, from upstream catchments to downstream ones. Losses in upstream areas might contribute to discharge in downstream river stretches. Assuming that these losses are completely lost might produce an overestimation of the impacts in general and in some catchments in particular. This issue needs to be discussed

Authors: Referee#1 has made this comment above and we have answered it. We therefore do not repeat our answer here.

Referee #1 (p. 6, l. 24): this sentence is not clear to me

Authors: Thank you. Irrigating areas that were not irrigated before will potentially lead to increased water requirements upstream, and hence may lead to an altered water availability downstream Hence a fully dynamic, spatially distributed assessment would be required to account for this. Our study does not attempt to do this. We have revised this sentence. It now reads: “Note that in the case of expansion of irrigation on the rainfed cropping areas the approach applied here does not account for dynamic changes in regional water availability due to increased upstream water consumption and hence an altered water availability downstream.” (p. 7, lines 211 - 213)

Referee #1 (p. 7, l. 1): repeated: same as line 30, page 5

Authors: Thank you for spotting this. We would like to keep that statement to provide a complete explanation in this part of the text. But we should of course not repeat at complete sentence. We have rephrased the sentence and it now reads:

“For the irrigation expansion scenario, the growing areas of the crops considered have been upscaled using the proportion of crops grown in the reference scenario.” (p. 8, lines 222-224)

Referee #1 (p. 9, l. 2): average values are represented in Fig1?

Authors: The values for the study year 2012 are shown in this Figure.

Referee #1 (p. 9, l. 8): fracture?

Authors: Thank you. We have revised this sentence. It now reads: “Water consumption displays a distinct change in pattern from West to East (western areas: rainfed; eastern areas: irrigated).“ (p. 10, lines 288-289)

Referee #1(p. 9, l. 24): the two groups with the highest water availability seem to cover a quite limited area; please provide figures for areas of each group

Authors: We would prefer to not add more figures. We had added a focus area, i.e. the Cerrado, to our study, and the detailed results are presented in Table 3. Furthermore, the categorisation of levels of water availability for map display is rather arbitrary and we are not certain if plotting those 7 categories would in fact add value.

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Please also note the supplement to this comment:
https://www.hydrol-earth-syst-sci-discuss.net/hess-2019-174/hess-2019-174-AC1-supplement.pdf

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