We would like to thank Anonymous Referee # 2 for his/her interest in this topic and for the valuable comments to improve our manuscript. Our point-by-point response to the comments is given in the following:

General comments from referee

This paper analyses results of a previously applied hydrological model (gsflow) to assess green and blue water partitioning in the Heine basin in China. The paper is well written however unclear in his contribution and as a result it is difficult to judge if methods are tailored to the objectives or the objectives are a tailored to available results from previous studies. More specific comments follow:

Author's response

Thank you for the comment. The main contribution of our work includes the following. We did a thorough green and blue water assessment by investigating the blue and green water from both water supply and water consumption perspectives and considering the interaction between green and blue water, while conventional studies usually focus only on either water supply or water consumption and ignores the interlinkages between green and blue water. We used a sophisticated model to simulate the complex eco-hydrological processes by considering intensive human activities induced strong exchanges between surface water and groundwater, while traditional approaches using lumped or semi-distributed model might be insufficient to simulate all the necessary hydrological elements required by the analysis. We investigated green and blue water regime for different human and natural ecosystems in a detailed way and revealed the water competition dynamics between human and nature. These provide crucial implications for water management in an arid or semi-arid region and they are not shown by any other previous works.

Comment 1

The objectives of the paper state: "(1) How integrated hydrological modeling could efficiently and effectively simulate green and blue water dynamics while emphasizing the interlinkages between them; (2) How the implication of such green and blue water assessment could support basin-scale water resources management to address human-nature water conflicts." Both objectives are too generic. First, surely there are studies that have addressed these problems. The objectives of the paper need to reflect what this study does in addition. Second, this paper does not address these objectives in general. It is limited to a specific application in the Heine catchment. This needs to be reflected.

Author's response

Thank you very much for the comment. Regarding to the first objective "(1) How integrated hydrological modeling could efficiently and effectively simulate green and blue water dynamics while emphasizing the interlinkages between them;", we are sorry that we did not state it very clear here. Indeed there are many studies have been done on green and blue water resources assessment, as we have already mentioned in the introduction section. But studies that consider the complex interactions between green and blue water are rare. Even some of them integrated the interlinkages between green and blue water in the study by considering processes like irrigation and capillary rise, they still failed to provide a thorough analyzing regarding to explicit depiction of the dynamics, regimes and the corresponding implications for water management. In our work, the incoming and outgoing green water flow in the domain is not balanced. In this region, dense irrigation system, including water pumping from wells and water diversion from rivers, was build here due to the limited precipitation here. Intensive irrigation activities affects the water cycling dramatically, especially causing strong surface water and groundwater exchanges. We want understand not only how much of green and blue water flow in and flow out of the domain, but also how green and blue water transformed between each other to match the imbalanced green and blue water flow regime. This is one of the main objectives of our study. The model we used is capable to simulate both surface hydrology and groundwater hydrology, as well as explicitly consider irrigation, water diversion and groundwater pumping. This allows us to explicitly investigate the green and blue water dynamics by emphasizing the interlinkages between them. Based on the Referee's suggestion, we modified our first objectives as following.

Author's changes in manuscript

Page 3, Line 28.

original: "(1) How integrated hydrological modeling could efficiently and effectively simulate green and blue water dynamics while emphasizing the interlinkages between them;"

updated: "(1) How integrated hydrological modeling could efficiently and effectively simulate green and blue water dynamics while emphasizing the interlinkages between them in an arid endorheic river basin by explicitly consider irrigation, water diversion and groundwater pumping;"

Author's response

Regarding to the second objective "(2) How the implication of such green and blue water assessment could support basin-scale water resources management to address human-nature water conflicts.", we agree on the Referee's comment that the specific application in an arid catchment should be reflected. We have now modified it as following.

Author's changes in manuscript

Page 3, Line 30.

original: "(2) How the implication of such green and blue water assessment could support basin-scale water resources management to address human-nature water conflicts."

updated: "(2) How the implication of such green and blue water assessment could support basin-scale water resources management to address human-nature water conflicts in an arid endorheic catchment."

Comment 2

Title is too generic. It could be a good title for a book or for a conference session. It would be appropriate if the paper was so comprehensive to address a problem that was never addressed and to a level that the problem is definitely solved. It is not the case of an application of a model on the Heihe basin.

Author's response

Thank you for the suggestion. We agree that the title is too generic. As already mentioned in Response to Comment 1, we would like to use a appropriate hydrological model to improve understanding the hydrological interactions between green and blue water which is usually ignored by other studies. However, the interlinkages between green and blue water play critical roles in the water cycling, especially in the region with intensive human activities. We believe such thorough study could provide crucial implications for water management in arid and semi-arid catchment, especially for the regions that have both human and natural ecosystems. Based on the Referee's suggestion, We changed the title to "Assessing Green and Blue Water in An Arid Catchment: Understanding Interactions and Making Balance between Human and Nature"

Comment 3

The introduction speaks about geological eras and problems of mankind but should be tailored to the specific advances that the paper wants to make.

Author's response

Indeed, we mentioned in the introduction that the humanity's impact is so profound now and this could lead to increased pressure, competition and conflict over freshwater resources use between human and nature. It is exactly the reason we do the research on an catchment with intensive human activities which might threaten the natural ecosystems. In this work, we also did the analysis on the water competition between human and natural ecosystems. Results show that the blue water resources are used by human with a higher priority. This implies that the natural ecosystems will face increased risk over freshwater use if competition increases. Therefore, the mention of Anthropocene in the introduction section is necessary for this work.

Comment 4

The model selection is a crucial methodological choice. A fully distributed hydrological model is selected for the following reasons: "(1) This study aims to assess the water resources by investigating the interlink between green water and blue water. The selected model is capable to simulate all the necessary hydrological elements for this analysis due to the capacity of the model for detailed depiction of interactions between groundwater and surface water. (2) Gridded hydrological simulations from distributed model are essential for spatial investigation on green and blue water." Both arguments are not convincing. Re argument 1, what are all the necessary hydrological elements needed to assess green and blue water components? I struggle to see why one would need to model everything if interested only in such partitioning. Re argument 2, why gridded simulations are essential? Can one go with a couple of HRUs?

Author's response

Thanks for the comment. Response to argument 1 issue. One of the objectives of this study is to investigate the interlinkages between green and blue water in an area with intensive irrigation, while the irrigation system consists of groundwater and surface water irrigation infrastructures. To achieve the goal, in addition to simulate general surface water and groundwater hydrological elements, such as runoff, infiltration, groundwater recharge and so on, we have to also simulate the entire irrigation system in the domain. These simulations includes pumping water from wells, surface water diversion from rivers, seepage flow from canals and return flow to the rivers or groundwater. All above-mentioned elements that are necessary for this work are referred to the necessary hydrological elements in this study. We did not, theoretically cannot, model everything. In conclusion, necessary hydrological elements refer to the basic requirements of data or simulation for hydrological problems solving. For instance, analyzing the water balance in a basin without any human activities, the necessary hydrological elements for such study could be some general variables like precipitation, infiltration, evaporation and runoff.

Response to argument 2 issue. Indeed, spatial analysis can also be done with simulations on a couple of HRUs. We are sorry that we did not state it clear here. The advantage of grid-based model structure allows interaction between grid cells with a routing system. HRU-based model usually needs sub-basin delimitation and simulate for each sub-basins. Both of them allow for spatial investigation. However, grid-based model simulations could provide smooth information which can better reveal spatial heterogeneity. With the HRU-based (usually sub-basin scale) simulations, you will see gradients with suddenly changes. Based on the Referee's suggestion, we have modified our manuscript as following.

Author's changes in manuscript

Page 5, Line 2.

original: "(2) Gridded hydrological simulations from distributed model are essential for spatial investigation on green and blue water."

updated: "(2) Gridded hydrological simulations from distributed model are preferred for spatial investigation on green and blue water to reveal the spatial heterogeneity."

Comment 5

The calibration and validation of the model is deferred to another study. This limits the relative contribution of this paper to an analysis of already available results, and complicates the assessment of the appropriateness of methods.

Author's response

Thank you for the comments. We refer the calibration and validation to another study for the sake of avoiding the duplicate work that require high computing cost. Indeed, the model usually has to be calibrated and validated before application. The model we used is developed and well calibrated and validated by other study but in exactly the same regions. The same model setups, configurations and parameters are taken in our study. We believe it is fair to use it for another application without further calibration and validation in the same region. There are also other studies did it in the similar way. For instance, Döll et al. (2012) used the the calibration parameter values of WaterGAP 2.1g to run the version 2.1h for another application. We are sorry that we did not state clearly about the calibration and validation issues in the manuscript. We thus changed the description of this part accordingly (see it in the following section: Author's changes in manuscript).

We did not take the already available results for the analysis of this work. As we mentioned in the manuscript (Section 2.4), the model is run at 1 km x 1 km spatial resolution at daily scale. We run the model with well calibrated set-ups and configurations in the same region with improved driving forces. The simulations are then used for green and blue water analysis.

Author's changes in manuscript

Page 6, Line 4.

original: "Since the improved GSFLOW model has already been well calibrated and validated in this region by Tian, Zheng, Zheng et al. (2015a) and Tian, Zheng, Wu et al. (2015b), it is directly run for the study area without any further parameter tuning."

updated: "The model has already been well calibrated and validated in this region by Tian, Zheng, Zheng et al. (2015a) and Tian, Zheng, Wu et al. (2015b). In this study, the same set-ups and configurations including calibrated parameters are taken for the model. Therefore, it is directly run for the study area without any further parameter tuning."

Comment 6

There is no uncertainty analysis in this paper and no comparison with alternative models. Considering that green and blue water are derived quantities form a calibration on other type of data (ie streamflow), I suspect that there is large uncertainty in the analysis. Perhaps something that is difficult to do with such a complex model, but perhaps also something that would speak in favour of different methodological choices? It would be also good to see how different would results be if applying a much simpler model, and if there are arguments to prefer the results of one model over the other.

Author's response

Thanks for comment. Indeed, we did not analysis the uncertainty in this work. The reasons are followed. (1) Usually, the model is not calibrated directly on the green or blue water flow itself, as the blue or green water consists of a few hydrological fluxes. E.g. blue water flow refers to the sum-up of the surface runoff, subsurface runoff and groundwater recharge. Therefore, even green and blue water are analyzed, the model is still calibrated and validated on the traditional hydrological fluxes. (2) The model is calibrated and validated with streamflow, ground water table and evapotranspiration rather than only one variable (figures from Tian et al. (2015) are shown in the following.). This ensures the accuracy of the simulations.

We agree that it would be good to see the comparison with alternative models. We also tried on this. However, the research domain we selected is installed with intensive irrigation systems. It is hard to find another models that can also simulate such complex irrigation system and irrigation activities. Indeed, there are some models have been applied in HRB for hydrological simulation, e.g. SWAT (Zang et al., 2012; Zang et al., 2015). But these studies are mainly focus on the climate change or land used induced impacts on hydrological cycle. None of them is able to capture the characteristics of such complex irrigation system,. The model we used (it is named as HEIFLOW in Li et al. (2018)) is so far the only model that can simulate the complex irrigation system in HRB. This is due to the reason that this model is tailored for HRB under the support of a key research program "Integrated research on the eco-hydrological process of the Heihe River Basin" which is launched by National Natural Science Foundation of China since 2010.

Comment 7

The treatment of the interception process is unclear. It appears that intercepted water has been incorporated in green water, but as already noted by other reviewers, this may be inappropriate.

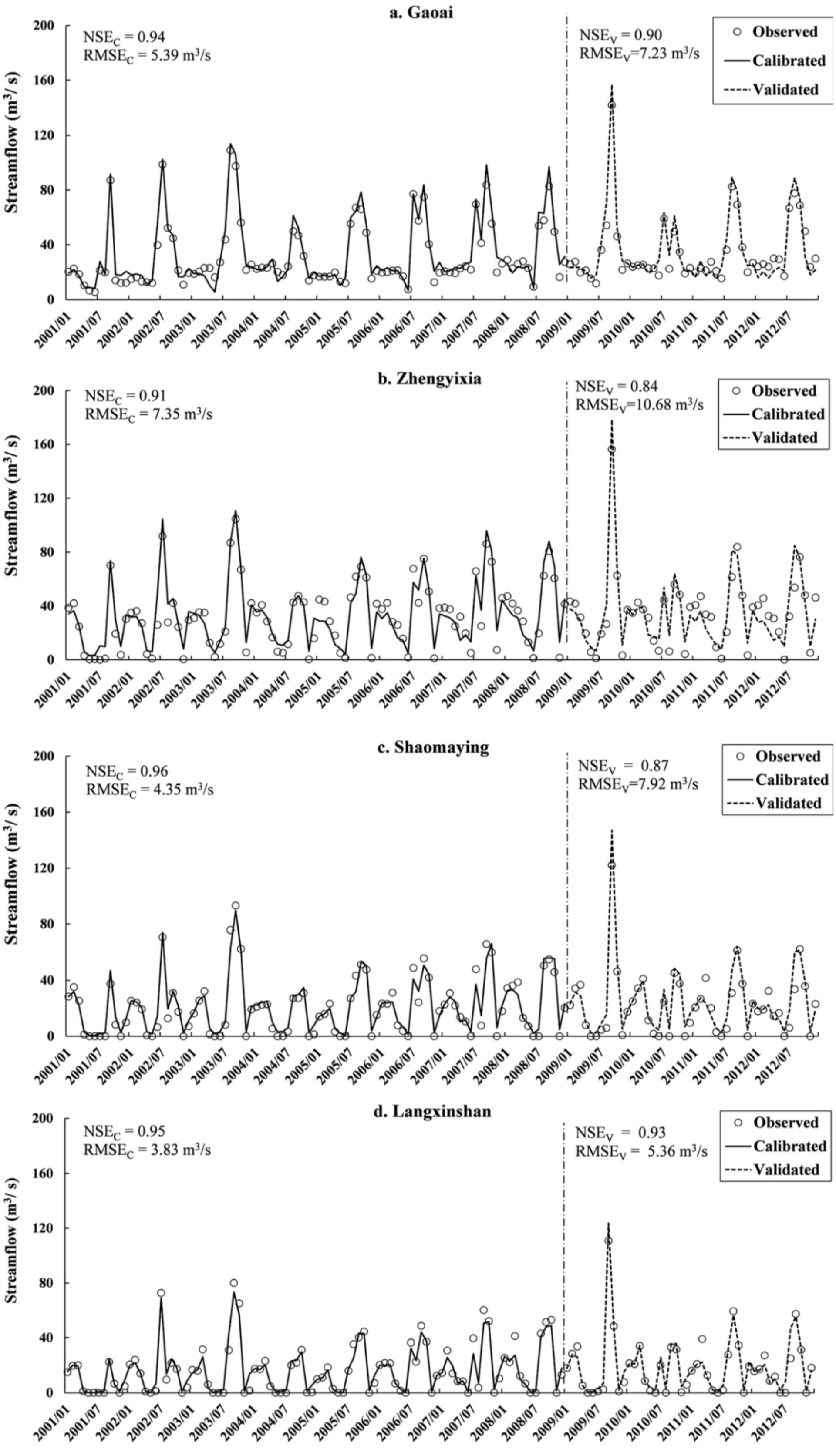

Figure 1: Comparison of simulated and observed monthly streamflow in both calibration and validation periods: (a) Gaoai station; (b) Zhengyixia station; (c) Shaomaying station; and (d) Langxinshan station. (Tian et al., 2015)

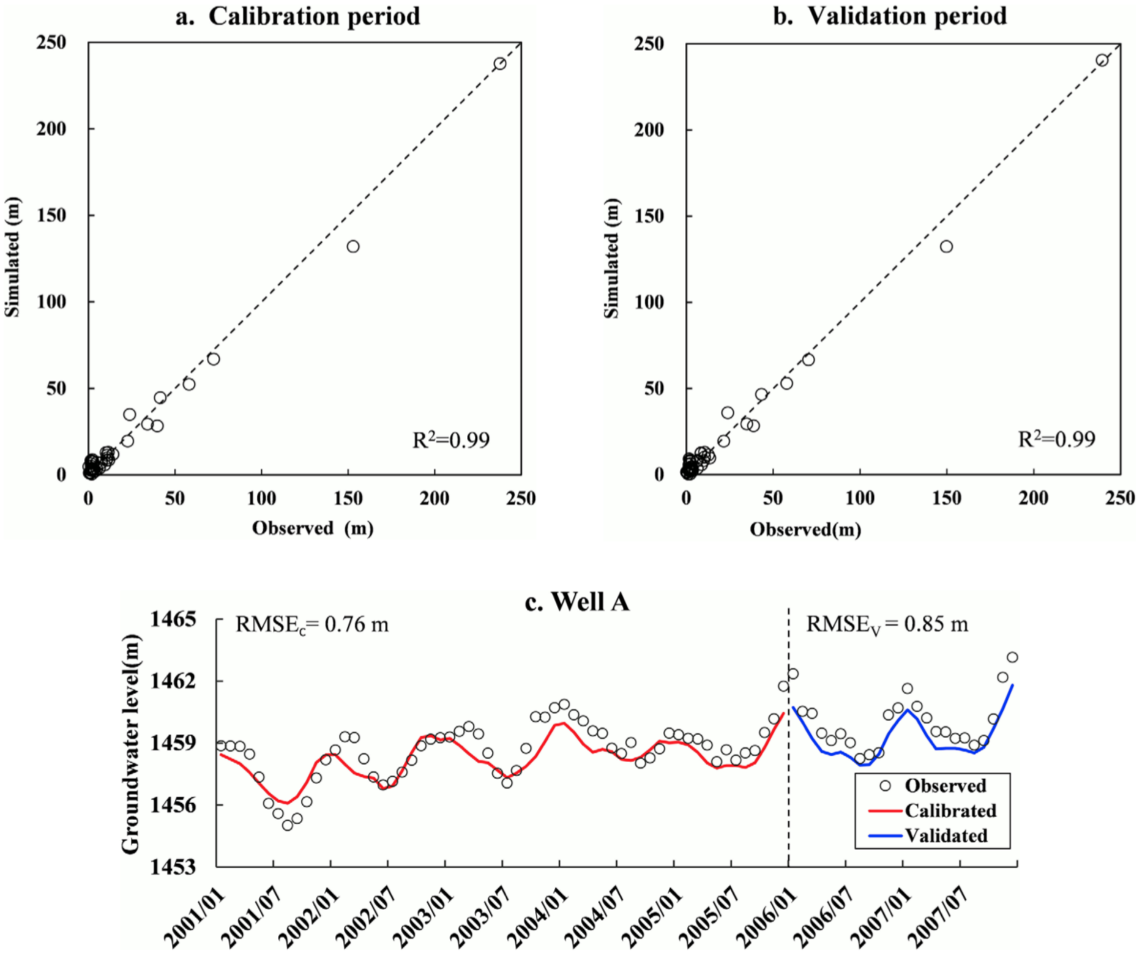

Figure 2: Calibration and validation results for groundwater. (a) Annual average depth to water table (DW) for the calibration period (2001–2005); (b) annual average DW for the validation period (2006–2007); (c) seasonal variation of the groundwater level at a well in the domian. (Tian et al., 2015)

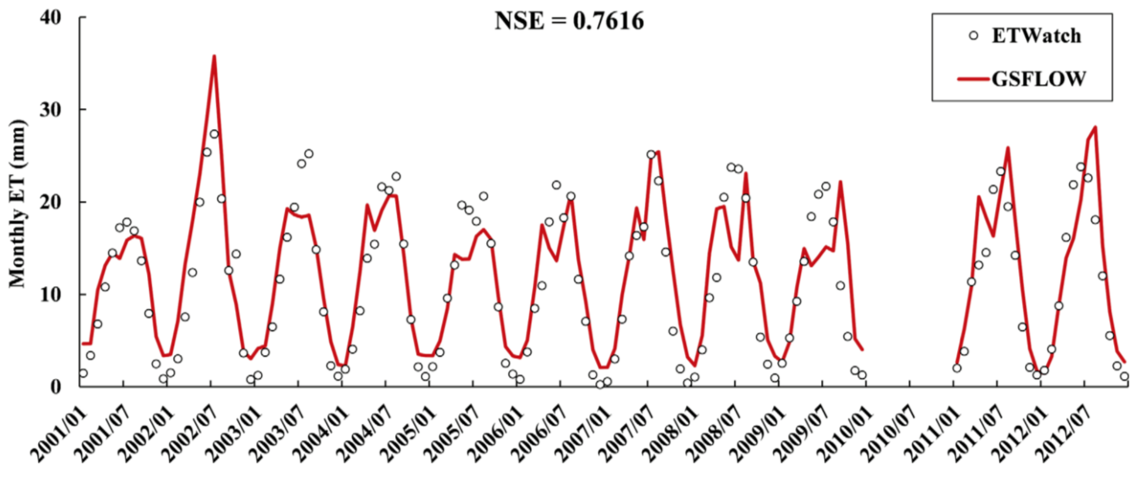

Figure 3: Comparison of monthly basin-wide ET simulations by the GSFLOW model and the ETWatch model. (Tian et al., 2015)

This comes back to clarifying what are the necessary processes to estimate green and blue water components (see point 4).

Author's response

Thank you for the comment. Indeed, we have originally incorporated the interception in green water as it is inherently a part of the green water. We also agree that the separation of interception from green water could improve the description of green and blue water flow regimes. We have addressed this issue already in the Response to RC1 Comment #1. We have also modified the text and figures in the manuscript accordingly. Please see the details in the Response to RC1 Comment #1.

Comment 8

Most conclusions are not related to the paper objectives

Author's response

Thank you for your comment. However, we cannot fully agree on this.

Our original objectives are "(1) How integrated hydrological modeling could efficiently and effectively simulate green and blue water dynamics while emphasizing the interlinkages between them; (2) How the implication of such green and blue water assessment could support basin-scale water resources management to address human-nature water conflicts."

Now the objectives are modified accordingly based on Referee's suggestions "(1) How integrated hydrological modeling could efficiently and effectively simulate green and blue water dynamics while emphasizing the interlinkages between them in an arid endorheic river basin by explicitly consider irrigation, water diversion and groundwater pumping; (2) How the implication of such green and blue water assessment could support basin-scale water resources management to address human-nature water conflicts in an arid endorheic catchment."

We here now list some of the conclusions.

"Even though the green water resources are the major resources in the research area - an arid river basin, the blue water resources from upstream are also crucial for the ecosystems in this region to meet the water demand. The transformation from blue water to green water plays a key role in the completed water cycling in this area as the water required for evaporation are extremely higher than the water stored in the root zone area (green water from precipitation)." This conclusion is based on the investigation of green and blue water dynamics and the interaction between them. All the data are simulated by an integrated hydrological model which is specified in the objective 1. Main results of this part shown in the Figure 3 in the manuscript. We believe it reflects the objective 1 of this work.

"Both the water availability and water consumption vary in time and space in the research area. Different hydrological processing mechanisms in ecosystems together with the spatial and temporal heterogeneity of water supply forms totally different green and blue water regimes in different ecosystems. The farmland ecosystem highly relies on the irrigation, while the forest relies on both the irrigation and capillary water. Both the grassland and desert ecosystems mainly rely on the green water from precipitation, while the desert ecosystem almost generates no runoffs." This conclusion is based on two key analyses. (1) the investigation of spatial and temporal variability of the green and blue water; (2) the explicit analysis of green and blue flow regime in different ecosystems. All the analyses are highly rely on the integrated model simulations, especially the hydrological elements that reflect the interlinkages between green and blue water. The corresponding results are shown in Figure 4-6 in the manuscript. We believe this conclusion reflects the objective 1 of this work.

"The historical relationship between human water use and nature water use indicates that the blue water resources are used by human with a higher priority. Water consumption ratio of human increases with the decrease of the water availability. The natural ecosystems may take a higher pressure when the water competition between human and nature increases." This conclusion is based on the analysis of water consumption dynamics between human and nature. Such analysis reveals that the water used by human dramatically narrow down the water resources for nature. The corresponding results are shown in Figure 7 in the manuscript. We believe this conclusion reflects the objective 2 of this work.

References

Döll, P., Hoffmann-Dobrev, H., Portmann, F. T., Siebert, S., Eicker, A., Rodell, M., Strassberg, G. and Scanlon, B. R.: Impact of water withdrawals from groundwater and surface water on continental water storage variations, J. Geodyn., 59–60, 143–156, doi:10.1016/j.jog.2011.05.001, 2012.

Tian, Y., Zheng, Y., Zheng, C., Xiao, H., Fan, W., Zou, S., Wu, B., Yao, Y., Zhang, A. and Liu, J.: Exploring scale-dependent ecohydrological responses in a large endorheic river basin through integrated surface water-groundwater modeling, Water Resour. Res., 51(6), 4065–4085, 2015.

Zang, C., Liu, J., Velde, M. van der and Kraxner, F.: Assessment of spatial and temporal patterns of green and blue water flows under natural conditions in inland river basins in Northwest China, Hydrol. Earth Syst. Sci., 16(8), 2859–2870, 2012.

Zang, C., Liu, J., Gerten, D. and Jiang, L.: Influence of human activities and climate variability on green and blue water provision in the Heihe River Basin, NW China, J. Water Clim. Chang., 6(4), 800–815, 2015.

Li, X., Cheng, G., Ge, Y., Li, H., Han, F., Hu, X., Tian, W., Tian, Y., Pan, X., Nian, Y., Zhang, Y., Ran, Y., Zheng, Y., Gao, B., Yang, D., Zheng, C., Wang, X., Liu, S. and Cai, X.: Hydrological Cycle in the Heihe River Basin and Its Implication for Water Resource Management in Endorheic Basins, J. Geophys. Res. Atmos., n/a-n/a, doi:10.1002/2017JD027889, 2018.