The manuscript provides an in-depth analysis of water scarcity in the Yellow River Basin (YRB) using an integrated analytical framework. The study spans from 1965 to 2013, focusing on critical indicators like the Water Scarcity Index (WSI), frequency, duration, and exposed population. It also projects future water demand and evaluates potential solutions, particularly improving irrigation efficiency.

General Comments

The study addresses a crucial topic in hydrology and water resources management, particularly for a region as significant as the YRB. Integrating historical data, model simulations, and future projections provides a comprehensive overview. However, several areas could benefit from further clarification and refinement.

Response: We greatly appreciate your professional review of our article. As you have noted, several issues need to be addressed. According to your valuable suggestions, we will make the necessary corrections to our current manuscript. The detailed corrections are listed below.

R2C1: In the introduction, the authors list the limitations of previous studies regarding water use and water withdrawal estimation, highlighting their implications for water stress assessments. While the study acknowledges these limitations and aims to address them, many of the same uncertainties are reiterated in the uncertainty section (section 4.3). This raises the question: if these limitations remain largely unresolved, why emphasize them in the introduction?

Response: Thanks for your comment. One of the key innovations of this study, which distinguishes it from previous research, is the use of **long-term historical observed water use data** (Zhou et al., 2020) to evaluate the evolution of water stress from 1965 to 2013. In response to your suggestion (Comment 7), we will make every effort to extend this dataset by collecting recent publicly available data (from 2014 to the present) and update the related analysis. Further**, we will predict future water demand based on the trajectories of updated observed water withdrawals during recent years as the business-as-usual scenario (please also see our responses to Comments 6 and**

7). As stated in the uncertainty section, we acknowledge that this prediction may introduce some uncertainties and limitations due to technological advancements and population growth. However, predicting near-term future (2030s) water demand based on recent observed data may significantly reduce uncertainty. **More importantly, compared with methods based on macroscale socio-economic datasets, the use of observed water withdrawal data for water stress estimation ensures that the analysis of historical periods (spanning nearly six decades) is more reliable. Additionally, this water withdrawal dataset encompasses four major sectors, allowing us to further separate the effects of individual sectoral water withdrawals on changes in water stress.**

References:

Zhou, F., Bo, Y., Ciais, P., Dumas, P., Tang, Q., Wang, X., Liu, J., Zheng, C., Polcher, J., Yin, Z., Guimberteau, M., Peng, S., Ottle, C., Zhao, X., Zhao, J., Tan, Q., Chen, L., Shen, H., Yang, H., Piao, S., Wang, H., and Wada, Y.: Deceleration of China's human water use and its key drivers, Proc. Natl. Acad. Sci. USA, 117, 7702, 10.1073/pnas.1909902117, 2020.

R2C2: The authors' statements in the introduction about the limitations of previous studies using coarse spatial resolution global water scarcity assessments (e.g., 0.5° × 0.5° level) and neglecting upstream water availability are partly valid. However, there are existing studies that have addressed water scarcity in the Yellow River Basin (YRB) at a higher resolution, considering sub-basin scales and upstream water availability (e.g., Albers et al., 2021; Omer et al., 2020; Xie et al., 2020). Given this and the previous comment, the authors should revise the motivation section of the introduction accordingly.

Response: Thank you for providing these references. We will revise this section, as follows:

A substantial body of previous studies in China has explored the general features of water stress in the YRB at various spatial scales, ranging from provincial or prefectural levels (Zhao et al., 2015; Huang et al., 2023), to river basin scale (Yin et al., 2020), sub-basin scale (Zhou et al., 2019; Xu et al., 2022), and grid scales (Zhuo et al., 2016; Liu et al., 2019). Recently, considering quality requirements, a comprehensive assessment of nationwide water stress at multiple temporal and geographic scales has been conducted in China (Ma et al., 2020a). These assessments have significantly advanced our understanding of current water scarcity conditions. However, upstream inflows and water consumption were usually not taken into account in these studies. The neglection of upstream water availability means that downstream water stress will be overestimated (Munia et al., 2020; Sun et al., 2021). Previous work in China showed that the difference in the population affected by severe water stress was 60% with and without consideration of upstream water resources, which is even larger in northern water-limited areas (Liu et al., 20119). Incorporating upstream flows and water consumption offers a more reasonable assessment of water stress in the real world. **Some studies have made significant progress in understanding water stress in the YRB by considering upstream components, reservoir operations, or water transfer projects** (Albers et al., 2021; Omer et al., 2020; Xie et al., 2020; Sun et al., 2021). **Yet, they often covered short periods (less than 20 years), thus precluding a comprehensive documentation of the temporal dynamics of water stress.**

References:

Albers, L. T., Schyns, J. F., Booij, M. J., and Zhuo, L.: Blue water footprint caps per sub-catchment to mitigate water scarcity in a large river basin: The case of the Yellow River in China, J. Hydrol., 603, 126992, https://doi.org/10.1016/j.jhydrol.2021.126992, 2021.

Omer, A., Elagib, N. A., Zhuguo, M., Saleem, F., and Mohammed, A.: Water scarcity in the Yellow River Basin under future climate change and human activities, Sci. Total Environ., 749, 141446, https://doi.org/10.1016/j.scitotenv.2020.141446, 2020.

Xie, P., Zhuo, L., Yang, X., Huang, H., Gao, X., and Wu, P.: Spatial-temporal variations in blue and green water resources, water footprints and water scarcities in a large river basin: A case for the Yellow River basin, J. Hydrol., 590, 125222, https://doi.org/10.1016/j.jhydrol.2020.125222, 2020.

R2C3: The manuscript mentions the use of the SWAT model for simulating natural water availability. While the validation against hydrological station data is noted in section 2.4, detailed validation results and statistics (e.g., NSE, R2, P-factor, and R-factor) were not provided in the manuscript. These metrics are important to assess and understand the model's performance comprehensively.

Response: In our previous study (Zhang et al., 2024), we used the Nash–Sutcliffe efficiency (NSE) and the coefficient of determination (R^2) to evaluate the performance of the SWAT model. The figure below depicts monthly comparisons between modeled and observed streamflow at 11 hydrological stations during the calibration and validation periods. Generally, the SWAT model performed well in most cases, showing better performance for stations along the main stream than those along the tributaries, indicated by the higher NSE and R^2. Specifically, both the NSE and R^2 were > 0.7 at five main hydrological stations in both the calibration and validation periods and both the NSE and R^2 were > 0.6 (except the Zhuangtou) at five tributary hydrological stations, suggesting that the SWAT model can well capture the temporal variations in streamflow and can be used to simulate the water availability in the Yellow River basin.

We will also include the model performance evaluation in the revised version, which will be provided in the supplementary materials.

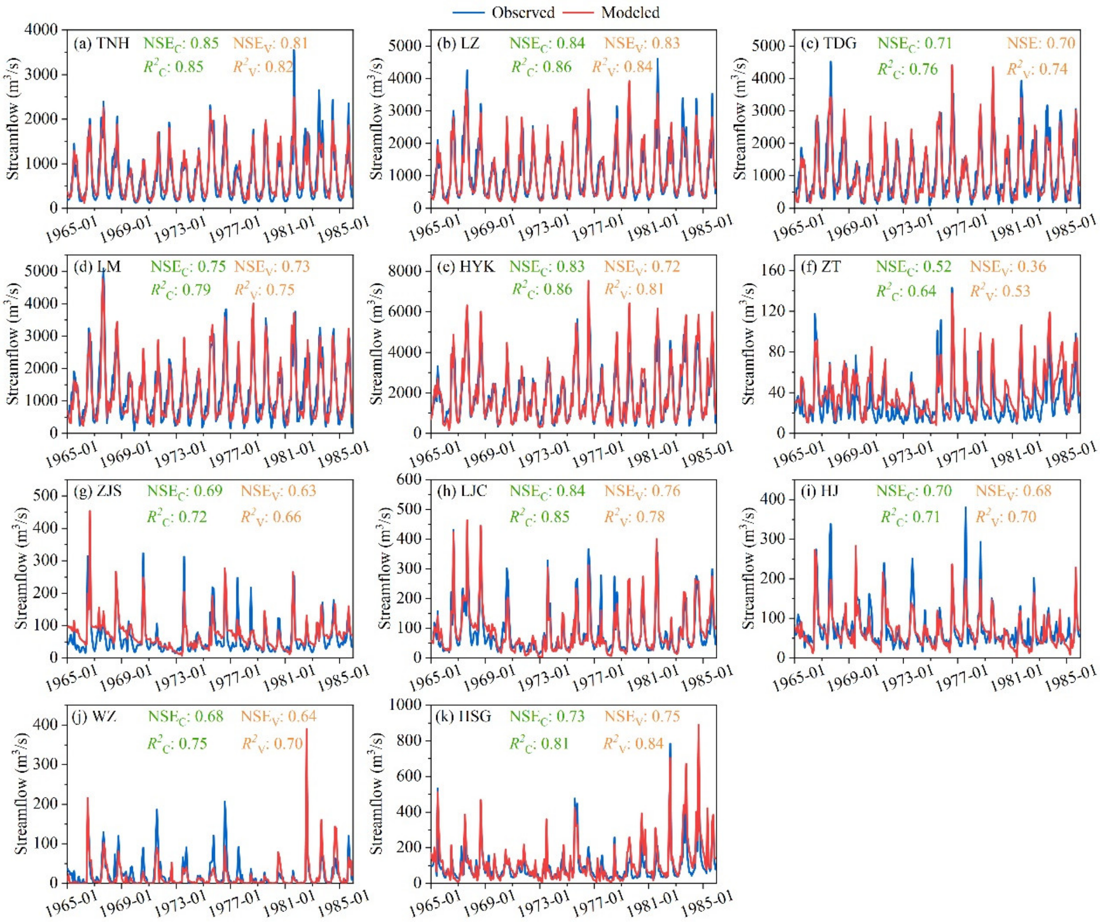

Figure Comparison between the monthly observed natural streamflow and modeled streamflow in calibration (1965–1975) and validation (1976–1985) periods for 11 hydrological stations. Abbreviation for hydrological stations: TNH = Tangnaihai, LZ = Lanzhou, TDG = Toudaoguai, LM = Longmen, HYK = Huayuankou, ZT = Zhuangtou, ZJS = Zhangjiashan, LJC = Linjiacun, HJ = Hejin, WZ = Wuzhi, and HSG = Heishiguan. NSE_C (R^2_C) and NSE_V (R^2_V) indicate the Nash-Sutcliffe efficiency values (the coefficient of determination) of the calibration and validation period, respectively.

R2C4: In section 2.4 the authors re-run the SWAT model with fixed land use in 1990 but varied climatic conditions to assess the impact of vegetation restoration. By fixing land use to the conditions of 1990, the model controls for the influence of land cover and land use changes. Any changes observed in water availability or WSI in this experiment can thus be attributed solely to climatic variations NOT vegetation restoration, isn't it?

Response: Thanks for your seriousness. We feel sorry for any incomplete descriptions in the original manuscript. In the original study, we run the model using climatic data from 2000 to 2013 and land cover data from 2010 under a normal scenario. To assess the impact of vegetation restoration on water availability, we re-run the model with fixed land cover from 1990, maintaining the same climatic conditions as in the normal scenario (2000–2013). The difference observed can be attributed to the impacts of vegetation restoration. In the revised version, as suggested in Comments 6 and 7, we will try our best to extend the dataset and use the same scenario analysis to quantify the effects of vegetation restoration.

R2C5: The introduction section in the study highlights a 120% increase in total water consumption, including both surface and groundwater, in the YRB from the 1960s to 2009. However, upon reviewing the methods and results sections, it is apparent that groundwater pumping and usage were not directly factored into the water availability calculations used in the water scarcity equation. Omitting this factor may lead to an underestimation of water availability and, thus, an overestimation of water scarcity levels.

Response: Thank you for your careful review. **In our water stress assessment, water availability refers to renewable water resources in rivers** (Yin et al., 2017; Wada et al., 2011), including surface, lateral flow, and baseflow, as simulated by the SWAT model. **The baseflow represents water from the shallow aquifer that returns to the reach. Thus, we indirectly considered the impact of groundwater.** Previous studies have reported that (Huang et al., 2021; Veldkamp et al., 2017), the absolute values of water storage in groundwater aquifers are difficult to estimate and often unknown. Consequently, we did not account for these non-renewable water resource components in our assessment. However, as you indicated, this approach may underestimate water availability in regions heavily dependent on groundwater resources, potentially leading to a lower anticipated water stress level in reality. **A more detailed explanation of the calculation of available water resources will be included in the methods and uncertainty sections of the revised version.**

References:

Huang, Z., Yuan, X., and Liu, X.: The key drivers for the changes in global water scarcity: Water withdrawal versus water availability, J. Hydrol., 601, 126658, https://doi.org/10.1016/j.jhydrol.2021.126658, 2021.

Veldkamp, T. I. E., Wada, Y., Aerts, J. C. J. H., Döll, P., Gosling, S. N., Liu, J., Masaki, Y., Oki, T., Ostberg, S., Pokhrel, Y., Satoh, Y., Kim, H., and Ward, P. J.: Water scarcity hotspots travel downstream due to human interventions in the 20th and 21st century, Nat. Commun., 8, 15697, 10.1038/ncomms15697, 2017.

Wada, Y., van Beek, L. P. H., and Bierkens, M. F. P.: Modelling global water stress of the recent past: on the relative importance of trends in water demand and climate variability, Hydrol. Earth Syst. Sci., 15, 3785-3808, 10.5194/hess-15-3785-2011, 2011.

Yin, Y., Tang, Q., Liu, X., and Zhang, X.: Water scarcity under various socio-economic pathways and its potential effects on food production in the Yellow River basin, Hydrol. Earth Syst. Sci., 21, 1-29, 10.5194/hess-21-791-2017, 2017.

R2C6: The study's prioritization of water use sectors during future water stress periods aims to mitigate socio-economic impacts by focusing on essential needs. However, this approach is unreliable due to two-sided uncertainties. First, using past period (P4: 2000-2013) water availability to calculate future water deficits ignores the high variability in water availability and the impacts of global climate change, making stationarity an invalid assumption. Second, projecting future water demands based solely on historical trends fails to account for potential changes in socio-economic dynamics and policies, which could significantly alter future demands. While the authors acknowledge the limitations of using P4 water availability and historical water demand trends, I think the resulting water allocation prioritization remains unreliable for policymakers. Addressing uncertainties on at least one side would improve the reliability of the prioritization framework.

Response: Thank you for your insightful comment. As you are concerned, we also observed an overall downward trend in water stress in the study area after 2003, resulting in slightly higher water stress during the period 2000–2013 compared to the 1990s (1.17 versus 1.12). The Chinese government has implemented more stringent water management policies since 2012, leading to stagnation or even a decrease in water withdrawal in some regions (Huang et al., 2023). According to the latest Water Resources Bulletin of the Yellow River basin (2014–2020), irrigation and industrial water withdrawals show an insignificant and significant ($p<0.05$) decreasing trend, respectively, at the basin scale. Combined with a significant upward trend in domestic water withdrawal, the total water withdrawal has remained relatively constant. As a result, water availability has slightly increased, leading to a decrease in overall water stress in the basin.

At the sub-basin scale, however, we need to collect more detailed human water withdrawal data at finer scale (grid, prefectural, or provincial levels). Moreover, we will collect recent meteorological data and rerun the model to calculate available water and corresponding water stress. **Overall, using the best available information, we aim to extend the study period (1965–2013) and conduct an analysis similar to the current study.** Previous studies in this basin, based on multiple model predictions, **indicate that projected changes in runoff are not significant during the 2000 to 2030 period (Yin et al. 2017; Yin et al. 2020).** Therefore, we mainly focus on the impacts of water use on future water stress. **Meanwhile, instead of the original linear trend forecasting method, we will use the autoregressive integrated moving average (ARIMA) to predict future water demand.** ARIMA is a well-established and effective linear statistical model for time series forecasting that considers both trends and white noise, and is widely used in water demand forecasting (Adamowski et al., 2012; Kavya et al., 2023). We believe that forecasting near-term future water demand (2030s) based on the trajectories of updated water use data with the ARIMA method can significantly reduce uncertainty. **Furthermore, we will collect newly published policies** (e.g., the 14th Five-Year Plan for water resources in various cities and provinces in the Yellow River basin) **to accurately assess the impacts of irrigation efficiency improvements on alleviating future water stress**. We expect that these efforts will enhance the reliability of this manuscript.

References:

Adamowski, J., Fung Chan, H., Prasher, S. O., Ozga-Zielinski, B., and Sliusarieva, A.: Comparison of multiple linear and nonlinear regression, autoregressive integrated moving average, artificial neural network, and wavelet artificial neural network methods for urban water demand forecasting in Montreal, Canada, Water Resour. Res., 48, https://doi.org/10.1029/2010WR009945, 2012.

Huang, Z., Yuan, X., Liu, X., and Tang, Q.: Growing control of climate change on water scarcity alleviation over northern part of China, Journal of Hydrology: Regional Studies, 46, 101332, https://doi.org/10.1016/j.ejrh.2023.101332, 2023.

Kavya, M., Mathew, A., Shekar, P. R., and P, S.: Short term water demand forecast modelling using artificial intelligence for smart water management, Sustainable Cities and Society, 95, 104610, https://doi.org/10.1016/j.scs.2023.104610, 2023.

Yin, Y., Tang, Q., Liu, X., and Zhang, X.: Water scarcity under various socio-economic pathways and its potential effects on food production in the Yellow River basin, Hydrol. Earth Syst. Sci., 21, 1-29, 10.5194/hess-21-791-2017, 2017.

Yin, Y., Wang, L., Wang, Z., Tang, Q., Piao, S., Chen, D., Xia, J., Conradt, T., Liu, J., Wada, Y., Cai, X., Xie, Z., Duan, Q., Li, X., Zhou, J., and Zhang, J.: Quantifying water scarcity in Northern China within the context of climatic and societal changes and South-to-North Water Diversion, Earth's Future, 8, e2020EF001492, https://doi.org/10.1029/2020EF001492, 2020.

R2C7: Additionally, the study's exclusion of the most recent decade (2013-2023) raises concerns. This period has seen significant changes in both water availability and demand, advances in data collection, and new policies and management practices. Incorporating recent data would provide a more accurate and up-to-date assessment of water scarcity in the Yellow River Basin (YRB), reflecting current conditions and offering a better foundation for future projections and management strategies. Including this recent decade would enhance the study's relevance and accuracy, making it more useful for policymakers.

Response: We acknowledge that the lack of data from the recent decade is a potential limitation of our study. Although your suggestion means a lot to us, **we will certainly make every effort to collect more human water withdrawal and meteorological data to rerun the model and conduct an analysis similar to the current study.** Furthermore, to accurately assess the impacts of irrigation efficiency improvements on alleviating future water stress, we will **incorporate newly published policies (please also refer to the above response).** It should be noted that, to maintain consistency with Zhou et al. (2020) (water withdrawal data used in the current study) and due to data access limitations, we may only be able to obtain water use data categorized by major sectors. Regardless, we believe that conducting the relevant analysis with updated data will provide valuable insights for policymakers.

R2C8: The manuscript effectively highlights potential improvements in irrigation efficiency as a key strategy for mitigating future water stress in the Yellow River Basin (YRB). However, it would benefit from a more comprehensive analysis or discussion on the feasibility of achieving these efficiency improvements.

Response: Thank you for your valuable comment. Based on your previous suggestion, **we will collect irrigation water efficiency targets from the latest water use policies of various provinces and cities within the Yellow River basin.** Then, we will further quantify the impact of future irrigation efficiency improvements on alleviating water stress, assuming that the current targets are achievable. In fact, according to previous water resource planning documents released by the Chinese government, these irrigation water efficiency targets are generally attainable (see the table below).

Table Irrigation efficiency in 2020 (target and actual). The underlined and bold texts indicate the provinces in the Yellow River basin

Provinces	Target	Actual	Provinces	Target	Actual
China	0.550	0.565	**Henan**	0.616	0.617
Beijing	0.750	0.750	Hubei	0.524	0.528
Tianjin	0.720	0.720	Hunan	0.540	0.541
Hebei	0.675	0.675	Guangdong	0.500	0.514
Shanxi	0.550	0.551	Guangxi	0.500	0.509
Inner Mongolia	0.550	0.564	Hainan	0.570	0.572
Liaoning	0.592	0.592	Chongqing	0.500	0.504
Jilin	0.600	0.602	**Sichuan**	0.480	0.484
Heilongjiang	0.600	0.613	Guizhou	0.486	0.486
Shanghai	0.738	0.738	Yunnan	0.492	0.492
Jiangsu	0.600	0.616	Xizang	0.450	0.451
Zhejiang	0.600	0.602	**Shaanxi**	0.580	0.579
Anhui	0.535	0.551	**Gansu**	0.570	0.570
Fujian	0.547	0.557	**Qinghai**	0.500	0.501
Jiangxi	0.510	0.515	**Ningxia**	0.530	0.551
Shandong	0.646	0.646	Xinjiang	0.570	0.570

Minor Comments

Figures and Tables:

R2C9: Figure 1 lacks a legend to explain the various elements used in the diagram. I think clarifying the meaning of the solid and dashed arrows, different rectangular colors, shapes, and outlines would help to understand the content of the figure.

Response: Thanks for your suggestion. We have revised Figure 1 and included the following explanations in the legend to enhance its clarity.

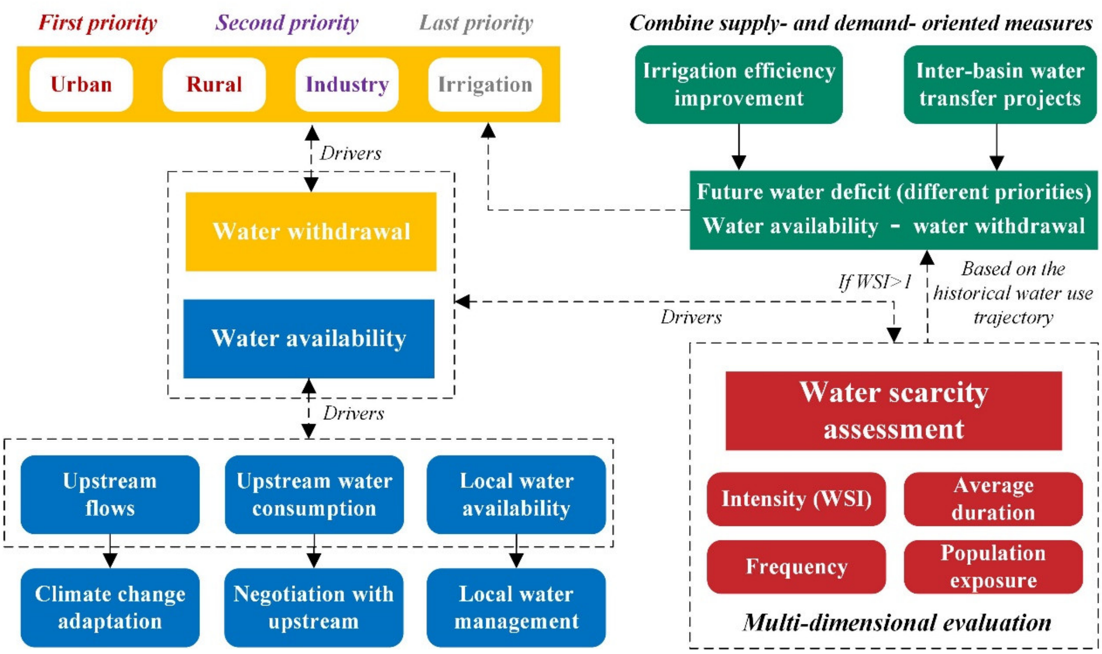

Figure 1. Framework for water scarcity assessment. The red, orange, blue, and green colors denote water scarcity assessment, water withdrawal, water availability, and future water deficit, respectively. The rectangle and rounded rectangles denote the main and detailed components of the above four parts, respectively. The dashed and solid arrows denote impact factors and solving measures, respectively.

R2C10: Figures 3, 4, and 7 are central to the manuscript's findings but could be clarified. Ensure that all figures have clear legends, labels, and units. Color gradients should be distinct enough for readers to differentiate between categories. Moreover, ensure all figures and tables are referenced in the text and clearly explained. For example, Figure 3 is mentioned, but its significance and interpretation could be better integrated into the discussion.

Response: In the revised manuscript, we will modify the color scheme, units, and labels in Figure 3 to enhance clarity and facilitate better interpretation of the data. Additionally, we will discuss the driving factors behind changes in water stress in the context of recently implemented water resources management policies. To our knowledge, few studies have examined the duration and frequency of water scarcity in this basin. Therefore, we will also discuss the implications and uncertainties associated with these results.

R2C11: The use of the terms and definitions: Throughout the manuscript, ensure consistent use of terms and clear definitions. For example, ensure terms like "water scarcity," "water stress," and "water availability" are defined clearly and used consistently to avoid confusion.

Response: Thanks for your seriousness. To avoid confusion, **we will standardize terminology and provide clear definitions**. In this study, we applied a very widely used indicator (WSI) to assess water stress conditions (defined as a ratio between water use and water availability, also see equation 1). A higher WSI value indicates more severe water stress conditions. Consistent with previous research (Veldkamp et al., 2017; He et al., 2020), a WSI value greater than 1 signifies that water resources are insufficient to meet both environmental and human needs, resulting in water scarcity. Water availability in this context encompasses locally generated runoff and incoming discharge from upstream sub-basins, taking into account environmental flow requirements (EFR) and upstream water consumption (Liu et al., 2019).

References:

He, C., Liu, Z., Wu, J., Pan, X., Fang, Z., Li, J., and Bryan, B. A.: Future global urban water scarcity and potential solutions, Nat. Commun., 12, 4667, 10.1038/s41467-021-25026-3, 2021.

Liu, X., Tang, Q., Liu, W., Veldkamp, T. I. E., Boulange, J., Liu, J., Wada, Y., Huang, Z., and Yang, H.: A spatially explicit assessment of growing water stress in China from the past to the future, Earth's Future, 7, 1027-1043, https://doi.org/10.1029/2019EF001181, 2019.

Veldkamp, T. I. E., Wada, Y., Aerts, J. C. J. H., Döll, P., Gosling, S. N., Liu, J., Masaki, Y., Oki, T., Ostberg, S., Pokhrel, Y., Satoh, Y., Kim, H., and Ward, P. J.: Water scarcity hotspots travel downstream due to human interventions in the 20th and 21st century, Nat. Commun., 8, 15697, 10.1038/ncomms15697, 2017.