Reply to Referee #3

Dear Reviewer

Thank you very much for your comprehensive review of our manuscript. We have endeavored to address all your comments as clearly as possible and have thoroughly revised the manuscript accordingly. Your insightful review has significantly enhanced the quality of our work. If any points remain unclear or require further clarification, we would be delighted to provide additional explanations.

On behalf of all authors, I would like to express our sincere gratitude for your rigorous and meticulous work.

Kind regards

Yang You

This manuscript developed a WSDR (Water Supply-Demand Risk) analytical framework based on the PLUS-InVEST model to InVESTigate the water supply-demand risks under 24 climate-land use change scenarios in the TRB, and to quantify the impacts of climate change and human activities on water supply-demand patterns and associated risks in the TRB. The study demonstrates a certain level of systematic analysis; however, substantial revisions are still needed in terms of textual presentation, results analysis, and discussion. The specific issues are as follows:

Q1: Further refine the scientific questions and highlight the key findings in the abstract.

Response: We sincerely thank you for this valuable suggestion. Based on a comprehensive review of the manuscript content and all reviewer comments, we have revised the abstract to better highlight the scientific question and clearly state the key findings.

Q2: The introduction is overly lengthy and should transition to the main topic more quickly. Moreover, it lacks a sufficient literature review on the limitations of existing water supply-demand studies and does not clearly articulate the novel contributions of this study.

Response: We sincerely appreciate your valuable comment. In response, we have revised and restructured the introduction of the manuscript. Regarding the literature review on limitations in water supply-demand research, the newly revised introduction now emphasizes the following key points in paragraphs 2-4:

(1) Under the combined impacts of climate change and human activities, the mismatch and dislocation between the natural endowment of water resources (in terms of spatial distribution and temporal variability) and human demands have further exacerbated regional water scarcity, making it increasingly difficult to meet both ecological and societal needs;(2) There remains a lack of systematic understanding of the relative contributions of climate change and human activities to water supply-demand balance, as well as how their interactions shape the spatial patterns and temporal evolution of supply-demand risks;(3) The application of coupled models such as PLUS-InVEST to deeply explore regional water supply-demand dynamics under climate change and agricultural irrigation remains limited.

Accordingly, identifying the response mechanisms of water supply-demand balance and risks under the combined effects of climate change and human activities (particularly agricultural practices) has become a critical scientific question to be addressed. Additionally, we have incorporated additional literature on water supply-demand research in the introduction, as detailed below:

Berdugo, M., Kéfi, S., Soliveres, S., & Maestre, F. T. (2017). Plant spatial patterns identify alternative ecosystem multifunctionality states in global drylands. Nature ecology & evolution, 1(2), 0003.

Li, C., Fu, B., Wang, S., Stringer, L. C., Wang, Y., Li, Z., ... & Zhou, W. (2021). Drivers and impacts of changes in China's drylands. Nature Reviews Earth & Environment, 2(12), 858-873.

Huang, J., Yu, H., Guan, X., Wang, G., & Guo, R. (2016). Accelerated dryland expansion under climate change. Nature climate change, 6(2), 166-171.

Chen, Y., Fang, G., Li, Z., Zhang, X., Gao, L., Elbeltagi, A., ... & Gao, Y. (2024). the crisis in oases: Research on ecological security and sustainable development in arid regions. Annual Review of Environment and Resources, 49.

Yan, H., Xie, Z., Jia, B., Li, R., Wang, L., Tian, Y., & You, Y. (2025). Impact of groundwater overextraction and agricultural irrigation on hydrological processes in an inland arid basin. Journal of Hydrology, 132770.

Chen, W., Li, G., Wang, D., Yang, Z., Wang, Z., Zhang, X., ... & Zhang, F. (2023). Influence of the ecosystem conversion process on the carbon and water cycles in different regions of China. Ecological Indicators, 148, 110040.

Furthermore, existing studies on arid regions have predominantly focused on the isolated impacts of either land use change (Zhu et al., 2023) or climate change (Lu et al., 2024; Hamed et al., 2024), while comprehensive investigations into their synergistic effects remain limited. However, previous research has emphasized that simulating water yield and assessing water supply-demand risks necessitate simultaneous consideration of both climate and land use changes (Guo et al., 2023; Liu et al., 2022). Therefore, it is particularly critical to evaluate the combined influence of these factors on water supply-demand dynamics and associated risks in arid regions. Based on this understanding, we explicitly highlight the novelty of this study in the concluding part of the introduction: by coupling multi-scenario analyses of climate and land use changes, we systematically assess their impacts on water supply-demand patterns and risks in a typical arid basin, and propose concrete and actionable management recommendations for optimizing water-land resource allocation and promoting agro-ecological sustainability in the region.

Q3: The description of the study area is insufficient. For example, the size of the basin is not provided, so it is unclear whether the basin is representative. It should be clarified whether a single basin can reflect the general conditions of arid regions. In addition, it is recommended to include spatial distribution maps of land use, precipitation, temperature, and evapotranspiration in the appendix to help readers better understand the basin.

Response: We sincerely thank you for this valuable suggestion. Your comment is highly significant for helping us more clearly describe the physiographic characteristics and typical representativeness of the study area. Accordingly, we have revised Section 2.1 (Study Area) by adding information regarding the spatial extent and representative features of the Tailan River Basin (TRB). In addition, we have included Fig. S1 in the Appendix, which illustrates the spatial distributions of key characteristic factors—including land use, precipitation, temperature, and potential evapotranspiration—within the TRB, to better support its representativeness.

Q4: In the land use scenarios, the land conversion probabilities range from 5% to 30%, which is a considerable variation. What is the rationale behind setting such a wide range of probabilities? How much uncertainty do these different probabilities introduce into the results?

Response: We sincerely appreciate your valuable feedback. The issue regarding the range of land conversion probability that you pointed out is indeed a critical aspect of our study. Below, I will address both the fundamental rationale and the associated uncertainties in separate points:

(1) Rationale for the probability settings:

The ranges we adopted were not based on subjective assumptions but were rigorously derived from extensive existing literature. Specifically, all six scenarios applied in our study are supported by the following references:

López, E.; Bocco, G.; Mendoza, M.; Duhau, E. Predicting land-cover and land-use change in the urban fringe: A case in Morelia city, Mexico. Landsc. Urban. Plann. 2001. 55(4), 271-285.

Liu, X.; Liu, Y.; Wang, Y.; Liu, Z. Evaluating potential impacts of land use changes on water supply-demand under multiple development scenarios in dryland region. J. Hydrol. 2022. 610, 127811.

Song, K., Cheng, W., Wang, B., & Xu, H. (2025). Impact of landform on Spatial-Temporal distribution and Scenario-Based prediction of carbon stocks in arid Regions: A Case study of Xinjiang. Catena, 250, 108781.

Liang, X., Guan, Q., Clarke, K. C., Liu, S., Wang, B., & Yao, Y. (2021). Understanding the drivers of sustainable land expansion using a patch-generating land use simulation (PLUS) model: A case study in Wuhan, China. Computers, Environment and Urban Systems, 85, 101569.

The aforementioned studies demonstrate that satisfactory simulation results were achieved under their respective probability settings. However, to mitigate the high responsiveness of specific scenarios in particular regions, and considering the unique characteristics of our study area (an arid oasis watershed—the Tailan River Basin), we carefully selected six scenarios from the above literature that are suitable for simulation in arid regions and align with the distinct features of the Tailan River Basin (arid climate, population centers, and ecological fragility). The selection criteria included:(a) similarity in geographical environment, and (b) similarity in land use types.

Furthermore, although the PLUS model (Liang et al., 2021) adopted in this study integrates a cellular automata (CA) model with a patch-generation simulation strategy to describe the attributes of land use change over specific time intervals, the natural and socio-economic conditions vary significantly across different patches within the Tailan River Basin (e.g., grasslands adjacent to croplands have much higher conversion potential than desert areas). This spatial heterogeneity necessitates an appropriate range of conversion probabilities (such as the 5–30% range set in this study).

Lastly, the land evolution process in a region is not only closely related to its natural characteristics but also profoundly influenced by national/provincial/regional development plans. Therefore, by setting a transfer probability range of 5–30% and employing multiple change scenarios, this study simulates the evolution of the Tailan River Basin over the next 30 years. This approach aims to provide governments and decision-makers with insights into possible future regional trajectories, potential development directions, and the flexibility to adjust strategies based on regional development requirements.

(2) Uncertainty of transition probability:

We fully agree with your concern about the uncertainties introduced by different probability settings. This is indeed one of the motivations for adopting multiple probabilities and scenarios in this study. As explained in the rationale above, uncertainties in land development arise from both natural evolution processes and multi-level government policy orientations. The direction of land development is not singular, which inherently introduces uncertainties. To reduce such uncertainties and enable governments/decision-makers to make more informed judgments about regional evolution, we simulated land development processes under different probabilities and scenarios. This provides empirical support for policy formulation and development planning. Thus, the original intention of this study was to reduce uncertainties in future land evolution processes, and the spectrum of probability variations was designed specifically to mitigate such uncertainties. Based on the above analysis, the probability settings adopted in this study are reasonable. Although the model outputs may carry uncertainties, the fundamental conclusions remain robust.

In summary, the 5–30% conversion probability range was determined based on a comprehensive decision-making process integrating literature review, practical needs, and policy analysis. This approach aims to better reduce the inherent uncertainties in future land use change. Simultaneously, this multi-probability, multi-scenario framework enhances our ability to reveal system responses under different pressures, thereby strengthening the depth and decision-support value of the manuscript. Your suggestion is highly valuable, and we have incorporated your comments along with the above perspectives into Section 4.4.

Q5: In the ecological protection scenario, only the conversion between other land types and construction land is considered. Why is the conversion between natural forests/grasslands and other land types not taken into account?

Response: We sincerely appreciate your valuable feedback. Firstly, the purpose of establishing the ecological protection scenario in this study is to expand ecological conservation areas and reduce human disturbances, thereby mitigating the encroachment of construction land on ecological land.

In the study area (the Tailan River Basin), forested land primarily exists in the form of shelterbelts with limited spatial extent and exhibits no significant conflicts with other land use types. Therefore, explicit conversion settings between natural forestland and other land categories were not incorporated. Secondly, grassland constitutes a prominent proportion of the study area (Tailan River Basin), while water bodies, forested land, and unused land remain relatively stable. Consequently, conversions between grassland and these three land types were not additionally configured. Furthermore, in accordance with China's 10th Five-Year Plan for National Economic and Social Development, the country strictly adheres to a designated "1.8 billion mu" cropland preservation (red line). To more prominently emphasize the impact of human disturbances (such as construction land expansion) on ecological systems, explicit conversion probabilities between cropland and grassland were not separately defined. This approach allows the study to better highlight the effects of anthropogenic activities on ecological land dynamics.

Q6: The figures should be made clearer. Please check whether all numbers and labels in the figures are explained to ensure that each figure is independently understandable. For example, what does the color bar in Figure 6 represent? What do the percentages in Figure 8 indicate?

Response: We sincerely appreciate your valuable feedback. We have thoroughly re-examined all figures and labels in the manuscript to enhance the self-explanatory nature of each chart. In particular, we have made focused revisions to Figures 6 and 8 as you suggested. Specifically, the color bar in Figure 6 represents the contribution degree of each factor, while the percentages in Figure 8 indicate the proportion of irrigation water demand relative to the total water demand. Thank you once again for your meticulous and diligent work.

Q7: Many of the statements in the results section lack data support and should avoid speculative or inferential language. For example, in line 399, the statement should be supported by relevant indicators quantifying land use structure. In line 403, the section does not analyze the driving factors of land use change—on what basis is the claim about cropland expansion made? In line 415, why is an external source cited—are the results derived from the data in this study? Are the statements in lines 454 and 470 supported by data?

Response: We sincerely appreciate your valuable feedback. We have thoroughly reviewed the discussion section and strengthened the supporting data for the results. The specific revisions are as follows:

(1) At line 399, we added relevant metrics to support the statement. The text has been revised to:

"Overall, the land use structure remained relatively stable across the multiple scenarios, with the most significant changes primarily manifested in cultivated land (33%) and grassland (29%) areas (Fig. 5)."

(2) At line 403, we supplemented the driving factor with the highest contribution to cultivated land change along with its numerical value. The text now reads:

"Notably, grassland area generally exhibited significant degradation (with an average reduction of 535.36 km^2), whereas cultivated land area expanded substantially (the contribution of population is the highest (0.22)) due to factors such as policy incentives and population growth (with an average increase of 524.87 km^2)."

(3) Regarding the description at line 415, the ambiguity may have arisen from our wording. We intended to indicate that the cited literature is consistent with our results. This sentence has been deleted to avoid confusion.

(4) Concerning your comments on lines 454 and 470, distinct differences can be observed in Fig. 7a (referenced at line 454) and Fig. 7b (referenced at line 470). Since Section 3.3 already includes extensive numerical descriptions of water supply and demand, we opted to avoid additional numerical details at these specific lines to maintain clarity and reduce potential confusion for readers and reviewers. Instead, we have added explicit references to Fig. 7a and Fig. 7b at the respective locations. Thank you once again for your meticulous and thoughtful review.

Q8: The discussion lacks depth and should include more references. It is recommended to expand the discussion based on the study's results, strengthen horizontal comparisons, and especially highlight similarities and differences with previous research.

Response: We sincerely thank you for your valuable comments. In response to your suggestions, we have implemented the following revisions:(1) We have increased the number of relevant references in the discussion section and thoroughly restructured its content. (2) Certain paragraphs have been reexamined and revised to more prominently highlight the distinctions between our study and previous research, with further emphasis on comparative analysis. The following additional references have been incorporated:

Lin, Y.P., Hong, N.M., Wu, P.J., Wu, C.F., Verburg, P.H., 2007. Impacts of land use change scenarios on hydrology and land use patterns in the Wu-Tu watershed in Northern Taiwan. Landscape Urban

Plan. 80 (1-2), 111-126.

Strokal, M., Bai, Z., Franssen, W. et al. Urbanization: an increasing source of multiple pollutants to rivers in the 21st century. npj Urban Sustain 1, 24 (2021).

Zhang Q, Peng J, Singh V P, et al. Spatio-temporal variations of precipitation in arid and semiarid regions of China: the Yellow River basin as a case study[J]. Global and Planetary Change, 2014, 114: 38-49.

Feng, Y., Sun, F., & Deng, X. (2025). Attributing the divergent changes of drought from humid to dry regions across China. Journal of Hydrology, 133363.

Zhang, Q., Singh, V. P., Sun, P., Chen, X., Zhang, Z., & Li, J. (2011). Precipitation and streamflow changes in China: changing patterns, causes and implications. Journal of Hydrology, 410(3-4), 204-216.

Dey, P., & Mishra, A. (2017). Separating the impacts of climate change and human activities on streamflow: A review of methodologies and critical assumptions. Journal of Hydrology, 548, 278-290.

Q9: Lines 579–581 state that the impact of climate change on water supply is far greater than that of land use change. However, based on the methodology, the climate scenarios and land use scenarios are not directly comparable. Is it appropriate to directly compare the magnitudes of their effects on water supply? The same concern applies to lines 598–601.

Response: We sincerely appreciate your valuable comments. This study examined the relationship between water supply and demand in the Tailan River Basin (TRB) under 24 combined land-climate scenarios. The water supply was calculated using the InVEST model (Equations 1-5), while water demand was computed through Equations (6-10), incorporating all 24-land use and climate change scenarios. This process yielded the multi-scenario water supply-demand results presented in Table 5.

Based on these data, we employed multi-factor analysis of variance (ANOVA) to analyze differences and variations in water supply and demand across the 24 scenarios. The results demonstrate that:

Climate change has a greater impact on water supply in the TRB compared to land use changes.

Land use changes exert a stronger influence on water demand in the TRB than climate change.

These findings are systematically summarized in the revised discussion section of the manuscript.

This finding is consistent with the original conclusions presented in the manuscript.

Q10: The methodology for identifying the driving factors influencing water supply, demand, and associated risks is not clearly described. The results appear to rely on the authors' assumptions and lack adequate data support. For example, in lines 577–579, it is recommended to include figures or tables showing how climate, soil, and vegetation influence water yield.

Response: We sincerely appreciate your valuable comments. Your suggestions are crucial for helping us develop a deeper understanding of the InVEST model used to simulate water supply.

Firstly, the InVEST model is widely applied in water yield simulation, and the water supply simulation relies on its water yield module. The fundamental principles of this module are illustrated in Equations (1) to (5).

Secondly, regarding water demand calculation, considering the regional characteristics of the Tailan River Basin (an arid oasis and population center) and its water use structure, the water demand in this study comprises three components: irrigation water demand, domestic water demand, and economic water demand. Notably, in calculating irrigation water demand, we innovatively incorporated Equations (6) and (7) to integrate the impact of climate change into the irrigation water demand process, thereby capturing the dual influences of climate and land use on water demand variations.

Based on this framework, we selected six land use change scenarios (NIS/FSS/EDS/EPS/WPS/BES) and four climate change scenarios (Land/S119/S245/S585), combining them pairwise to explore water supply and demand dynamics under 24 climate-land change scenarios. Using this approach and building on the water supply-demand risk calculation process proposed by Moran (2017), we established a water supply-demand risk assessment framework under the dual influences of climate and land use (Equations 9-12). The evaluation system is detailed in Table 4. Building upon this foundation, we employed methods such as analysis of variance and controlled variable approaches to clarify the differences and fluctuations in water supply and demand under the influence of 24 land-climate scenarios.

Within this framework, water supply and demand in the TRB region were calculated using Equations (1) to (10) in the manuscript, enabling the assessment of water supply-demand risks.

Regarding your comment on "lines 577-579, which mention a chart displaying how climate, soil, and vegetation affect water yield," we would like to clarify that the InVEST model is an integrated tool. Simulating water yield requires input data such as precipitation, potential evapotranspiration, root-restricting layer depth, plant available water content, land use, biophysical tables, and watershed boundaries. Additionally, parameters must be adjusted to adapt to the TRB region and achieve higher simulation accuracy (Fig. 4). However, due to the highly integrated nature of the InVEST model, it is challenging to isolate the independent effects of individual components (e.g., climate, soil, and vegetation) on water yield.

Your suggestion is immensely valuable for enhancing our understanding of the InVEST model. We have incorporated your feedback and related discussions into the research outlook section (Section 4.4) of this study. Furthermore, in future research, we will attempt to deconstruct the InVEST model to quantify the specific contributions of each component to water yield. Thank you once again for your insightful suggestions.

Q11: The discussion section contains redundant content, with many statements unrelated to the core findings of the study. It lacks in-depth attribution and mechanistic analysis of the results, as well as horizontal comparison with relevant literature. For instance, Section 4.1 extensively discusses the importance of land use and reiterates the land use scenario results and ecological implications, but pays limited attention to the mechanisms by which land use change affects water supply-demand dynamics. It is recommended to delete or simplify this section. The analysis of the number of driving factors influencing the model could be combined with the uncertainty analysis.

Response: We sincerely appreciate your valuable comments. We have reorganized and revised the discussion section as follows:(1) We have comprehensively revised the entire content of Section 4.1 in the manuscript, reducing the details on the mechanisms by which land use changes affect water resource supply-demand dynamics. (2) As highlighted in your comment Q8, we have further streamlined the discussion section, added relevant references, and placed greater emphasis on the core findings and innovations of this study. (3) We have enhanced the comparative analysis with related literature in the discussion section.

Q12: Please verify whether the logic in lines 591–592 is incorrect. There may be an inconsistency or misinterpretation in this statement.

Response: We sincerely appreciate your valuable feedback. We have reorganized the content in lines 591-592. The revised text now reads: "In arid regions, water supply exhibits a significant correlation with rainfall, and precipitation can explain a substantial portion of the variability in water availability (Adem et al., 2024). Notably, although water supply in humid areas is more sensitive to rainfall variations than in arid regions, the extreme scarcity of water resources in arid areas means that even minor changes in precipitation can lead to significant discrepancies in water supply-demand relationships. Consequently, arid regions face higher risks and vulnerability regarding water scarcity and thus require greater attention (Taylor et al., 2019)."

Q13: Provide supporting evidence for the statements made in lines 628–633. The manuscript does not appear to contain relevant research results or cited references to substantiate these claims.

Response: We sincerely appreciate your valuable comment. To accurately convey the notion that "there exists a complex interactive feedback mechanism between climate change and land use," we have referenced the study by (Qi et al., 2025), which elaborates on this interactive feedback mechanism in their research. Accordingly, the content in lines 628-633 has been revised as follows:" Normalized Difference Vegetation Index (NDVI) and Net Primary Productivity (NPP), subsequently altering crop phenology and water requirements, which induces changes in underlying surface land types (grassland, forest, and cultivated land). This cascade alters watershed runoff generation/concentration and evapotranspiration, ultimately feeding back to precipitation (Qi et al., 2025)."

Q14: Check whether the logic in lines 650–652 is flawed. The reasoning may be unclear or contradictory.

Response: We sincerely appreciate your valuable comment. In lines 650-652, we aimed to emphasize that water demand exhibits a trend, primarily driven by the expansion of cultivated land leading to increased irrigation requirements. Accordingly, we have revised the text as follows: "Within the framework of water supply-demand risk assessment in this study, water demand continues to rise over time, driven primarily by the expansion of cultivated land, which intensifies irrigation water requirements. This observation aligns with findings from previous reports (Qi et al., 2025)."

Q15: Streamline sentence expressions throughout the manuscript. Ensure that capitalization and punctuation are used correctly. For example, inconsistencies can be found in lines 54, 207,

210, 258, 357, and 476.

Response: We sincerely appreciate your valuable suggestion. We have thoroughly proofread the manuscript to refine punctuation and review grammatical expressions throughout the text.

In summary, your suggestions have been invaluable to the improvement of this manuscript. We have addressed each of your comments point-by-point, and the revisions made based on your recommendations have significantly enhanced the scientific rigor and precision of our work. On behalf of all co-authors, I would like to express our deepest gratitude for your thorough and meticulous review.