RC1

We are grateful for your thoughtful and constructive comments, which have provided invaluable guidance in strengthening our work. **In response to your feedback and the comments from reviewers #RC2 and #CC1, we have thoroughly revised the manuscript, and this is our second reply to your valuable comments.** Your comments are presented in red font, our responses in black, and the revisions to the manuscript in blue.

This multidisciplinary study on the Loess Plateau centers on surface–groundwater interactions and fits well within the scope of the Journal-HESS. Based on extensive field observations, the manuscript investigates groundwater recharge processes within gully systems on the Loess Plateau, aiming to reframe gullies as hydrologically active recharge zones rather than merely erosional landforms. The study uses an integrated, multi-method approach—including stable isotopes, chloride concentrations, water table fluctuation (WTF) analysis, and structural equation modeling (SEM)—to examine the linkages among precipitation, surface water, and different groundwater bodies. The authors have invested substantial effort in data collection, fieldwork, and laboratory analyses. Given the increasing importance of groundwater sustainability in arid regions, the study carries clear novelty and relevance, and makes several notable contributions: (1) Reframing the hydrological role of gullies in the loess hilly region (core innovation); (2) Identifying the key mechanisms and process chain of groundwater recharge within gully systems; (3) Demonstrating the significant enhancement of groundwater recharge by engineering interventions (check dams and ponds). Overall, the manuscript is of good quality but still lacks certain details. The following specific comments may help strengthen the paper. I recommend publication after moderate revision.

Response: Thank you for taking the time to review our manuscript and for providing valuable and constructive comments. Your feedback has greatly helped us improve the manuscript. We fully agree with your comments and have made substantial revisions to enhance its readability and academic rigor. Below are the specific changes we have made, along with our point-by-point responses to your comments.

1. Line 85-90: Clearly state the research goals to fully encompass the study content. It is

recommended to include a goal specifically addressing the analysis of isotopic characteristics, which will ensure alignment with your methodology and results.

Response: We fully accept your comment and have revised the research goals to include a specific focus on isotopic characteristics, ensuring alignment with the methodology and results. The specific revision is as follows:

"Therefore, this study selects the Nianzhuang Catchment, a typical gully area on the Loess Plateau impacted by check dams, to establish a multi-method framework for assessing groundwater recharge by integrating stable isotope analysis (δ^2H and $\delta^{18}O$), chloride concentrations, water table fluctuations, and hydro-statistical modeling. Specifically, our goals are to: (1) characterize the isotopic and hydrochemical signatures of precipitation, surface water (ponds), shallow pore water, and deeper fissure water; (2) identify and trace hydraulic connections and flow paths of different water bodies; and (3) quantitatively estimate pore-water recharge rates. This integrated approach aims to advance understanding of groundwater dynamics in complex dryland terrains, reframes engineered gully systems as critical recharge zones in engineered dryland landscapes, providing actionable insights for sustainable groundwater management and ecological restoration in the Loess Plateau and similar semi-arid regions worldwide."

2. Line 85-90: Rearrange the research goals to align with the structure of the results section, as the order of goals 1 and 2 appears to be reversed. The goals should follow the sequence in which the results are presented.

Response: We agree with your comment. The specific revision is as follows:

"(1) characterize the isotopic and hydrochemical signatures of precipitation, surface water (ponds), shallow pore water, and deeper fissure water; (2) identify and trace hydraulic connections and flow paths of different water bodies; and (3) quantitatively estimate pore-water recharge rates."

3. Line 180: How many wells in this catchment were monitored? Please show their positions in Figure 2.

Response: The monitoring network in this study includes 35 discrete sampling wells: 9 for pore water, and 26 for fissure water, aimed at characterizing the spatial variability of groundwater hydrochemistry and isotopic signatures. All sampling locations are clearly marked in Fig. 2 (in the original manuscript, and now Fig. 1 in the revised manuscript) of the original manuscript. Additionally, one continuous pore water table monitoring well is installed in the middle reaches of the catchment to quantify groundwater table fluctuations and estimate recharge rates. In response to your comment, we have updated Fig. 2 (in the original manuscript, and now Fig. 1 in the revised manuscript) to include the location of this monitoring well. The specific revisions are detailed below.

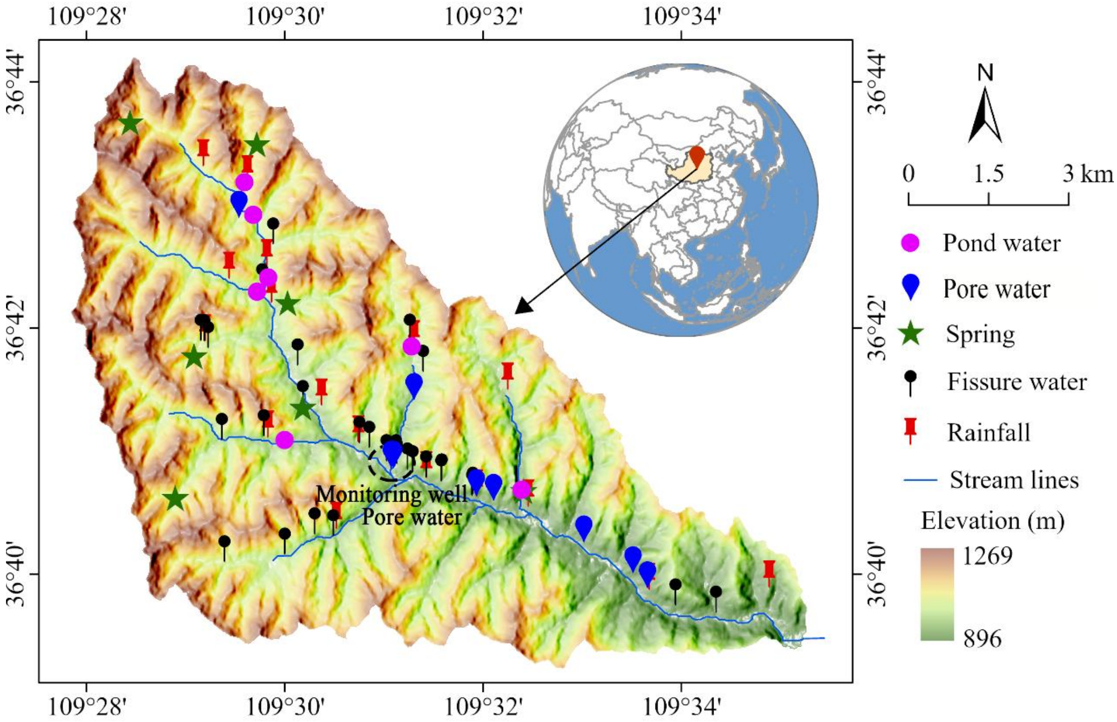


Fig. 1. The geographical location and sampling sites for rainfall, pond water, pore water, spring water, and fissure water in the Nianzhuang catchment. The Nianzhuang catchment is located in the hilly and gully region of the central Loess Plateau, with elevations ranging from 896 to 1269 m. The average depth of pore water wells is 8.0 ± 1.5 m (range: 4–10 m), while that of fissure water wells is 57.6 ± 29.2 m (range: 25–170 m). These sampling sites represent locations where both rainy and dry season samples were collected, and are all situated within the gully areas of the catchment.

4. It is recommended to unify the units in Line 235 ('m/day') and Line 214 ('m/d') for consistency. In addition, Line 213-214, the permeability of Neogene coarse sandstone and conglomerate here couldn't possibly be this (7.5–36.19 m/d) high. I suspect the authors might have made a mistake with the units. Please double-check.

Response: We fully agree with your comment and have made the necessary revisions. In the original manuscript, the permeability unit at Line 214 was listed as 'Lu' but was incorrectly noted as 'm/d'

(7.5–36.19 Lu ≈ 0.07–0.31 m/d). In this revision, all permeability units have been uniformly converted to the standard unit 'm/d' based on the conversion relationship and applied consistently throughout the manuscript. The specific revisions are detailed below.

"The significant reduction in loess thickness, combined with the relatively high permeability of Neogene coarse sandstone and conglomerate (0.07–0.31 m/d), creates favorable conditions for infiltration and focused recharge."

5. Line 494: The numbers in the global meteoric water line equation need to be superscripted.

Response: We have made the necessary revisions as per you commented, and the numbers in the global meteoric water line equation have now been superscripted. Thank you for pointing this out.

6. Line 614-629: When explaining the phenomenon that 'the isotopic values of most groundwater in the gully areas are more depleted compared to those of rainfall and pond water', ensure the logical connection between 'the thin unsaturated zone' and 'direct recharge from intense rainfall events' is fully articulated, and consider including a discussion on the 'seasonal precipitation isotope effect.

Response: We fully agree with your comment and have made the necessary revisions to clarify the logical connection between "the thin unsaturated zone" and "direct recharge from intense rainfall events". Additionally, we have included a discussion on the "seasonal precipitation isotope effect" to further enhance the explanation. The specific revisions are as follows:

"Additionally, the isotopic values of most groundwater in the gully areas are more depleted compared to those of rainfall and pond water, likely due to the recharge mechanisms and residence times of different groundwater types, and the inherent isotopic characteristics of their primary recharge sources (Ouali et al., 2024). The depleted signatures in groundwater reflect preferential capture of isotopically light summer monsoon events, with effective percolation delayed to cooler seasons due to transient soil storage and minimized evaporation, consistent with observed water table rises predominantly from October to April. Nevertheless, these values fall within the range of precipitation isotopic values, leaning towards the more negative end. This suggests two complementary mechanisms: (1) the thin unsaturated zone (<10 meters) provides preferential pathways for rapid infiltration of precipitation, minimizing evaporative fractionation, and (2) groundwater is likely recharged primarily by intense precipitation events (e.g., summer storms) with inherently more negative isotopic signatures (Liu et al., 2024). Together, these processes explain the observed isotopic characteristics of groundwater.”

Reference

Liu, Y.Z. Source analysis of precipitation chemical components on the Loess Plateau based on hydrogen and oxygen stable isotopes[D]. Northwest A&F University, 2024. DOI:10.27409/d.cnki.gxbnu.2024.001528.

7. Line 657-666: When describing the differences between previous studies and this research, it is essential to explicitly highlight the fundamental distinctions in 'spatial scale' and 'hydrological units' to more precisely define the original contribution of your work.

Response: We fully agree with this insightful suggestion and have revised the manuscript to explicitly highlight the fundamental distinctions in spatial scale and hydrological units between previous studies and our work. The specific revisions are as follows:

“In summary, while hillslope-scale studies describe a “dispersed recharge” mode, where precipitation percolates slowly through thick unsaturated zones, this study identifies a “concentrated recharge” mode in engineered gullies, driven by runoff convergence and regulated by check dams via ponding. These fundamentally distinct modes, differing in hydrological processes, spatial scales, and recharge efficiencies, collectively enhance the understanding of groundwater recharge mechanisms on the Loess Plateau.”

8. Line 807-815: When addressing the limitations of isotopes and structural equation modeling, the advantages of the Water Table Fluctuation (WTF) method should be articulated more precisely. Emphasize that these methods are 'complementary' rather than 'contradictory', thus presenting a more balanced argument.

Response: We fully agree with this constructive suggestion. To present a more balanced and precise argument, we have revised the relevant section to explicitly present the multi-method approach as complementary, rather than contradictory. The specific revisions are as follows:

“Without explicit mass-balance constraints, structural equation modeling may not independently or quantitatively represent actual groundwater flow processes. In contrast, the water-table fluctuation method, which directly measures changes in groundwater levels, provides a more empirically grounded estimate of total recharge. Each approach nevertheless offers distinct strengths: water-table fluctuations resolve the timing and magnitude of recharge, whereas isotopic, hydrochemical, and modeling analyses yield critical insights into recharge sources and flow pathways. By leveraging the complementarity and mutual corroboration of these methods, our study robustly demonstrates the pivotal role of gully areas in groundwater recharge.”

Figures and tables

1. Fig. 3a and 3c lack units on the x-axis. Additionally, the directions of profiles Line1 and Line2 should be clearly indicated in Fig. 3b.

Response: We appreciate your comment and have made the necessary revisions. The units on the x-axis have been added to both Fig. 3a and 3c. Additionally, the directions of the profiles Line1 and Line2 have been clearly indicated in Fig. 3b. The specific additions are as follows:

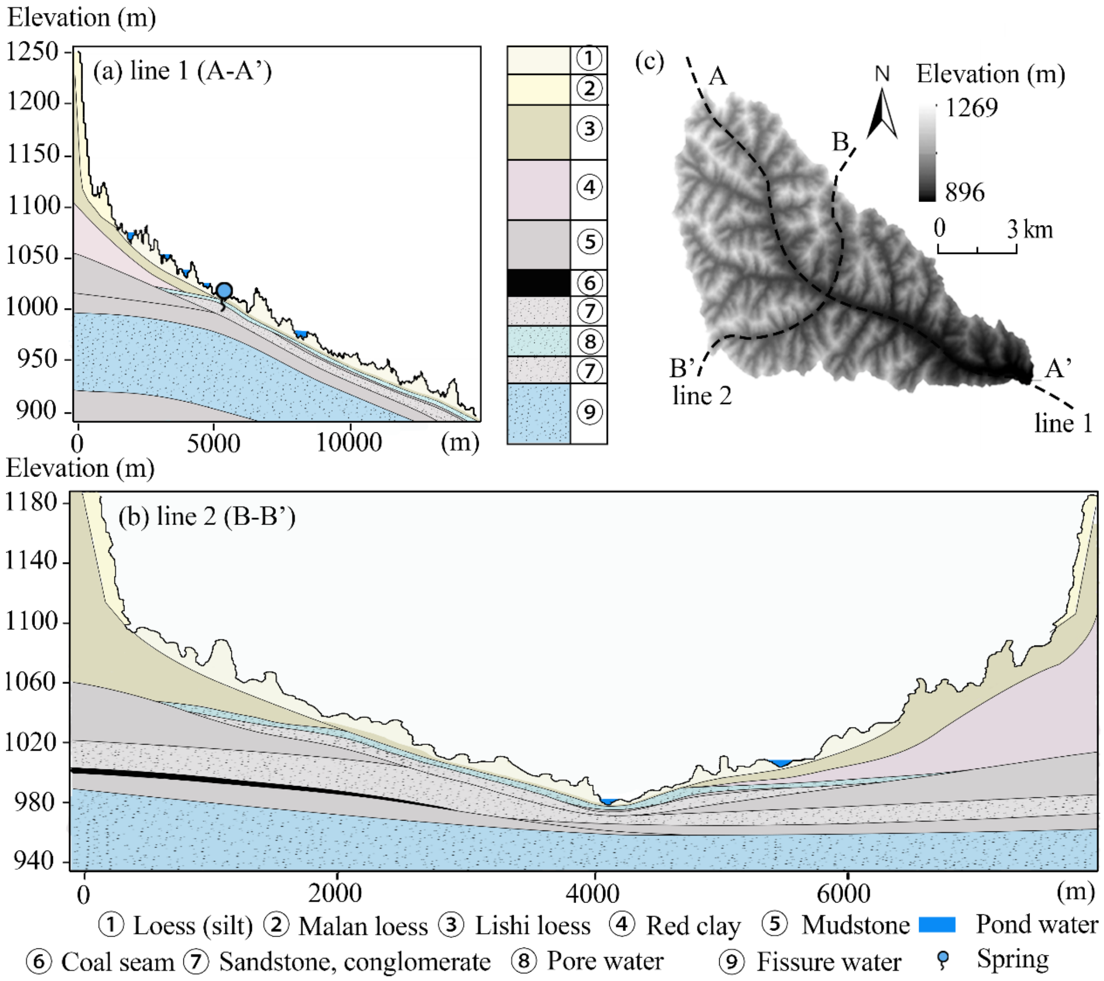


Fig. 3. Hydrogeologic cross-section of the study area. Cross-section along Line 1 (Northwest-Southeast) (a); cross-section along Line 2 (Southwest-Northeast) (b); location map of Line 1 and Line 2 within the

study area (c). The Malan Loess (11.7–12.6 Ka BP) and Lishi Loess (12.6–78.1 Ka BP) are two major Quaternary loess stratigraphic units in China. Based on hydrogeological research, the stratigraphy of the hilly region features a multi-layer structure from top to bottom: Upper Pleistocene Malan Loess, Middle Pleistocene Lishi Loess, Neogene Red Clay and Mudstone (2.58–23.03 Ma BP), and Jurassic Sandstone and Conglomerate (145–201.3 Ma BP). In the gully region, the stratigraphy includes Holocene loess (silt, 11.7 ka BP–present), Middle Pleistocene Lishi Loess, Neogene sandstone and mudstone, and Jurassic sandstone and conglomerate, with some areas containing coal seams up to 5 meters thick.

2. The terms 'Pore water table' and 'Porous water table' in Fig. 9a should be standardized for consistency.

Response: We have addressed this comment by standardizing the terminology in Fig. 9a (in the original manuscript, and now Fig. 10a in the revised manuscript), consistently using “Pore water table” throughout. Additionally, we have reviewed the entire manuscript and made similar revisions to ensure consistency across all related expressions. The specific additions are as follows:

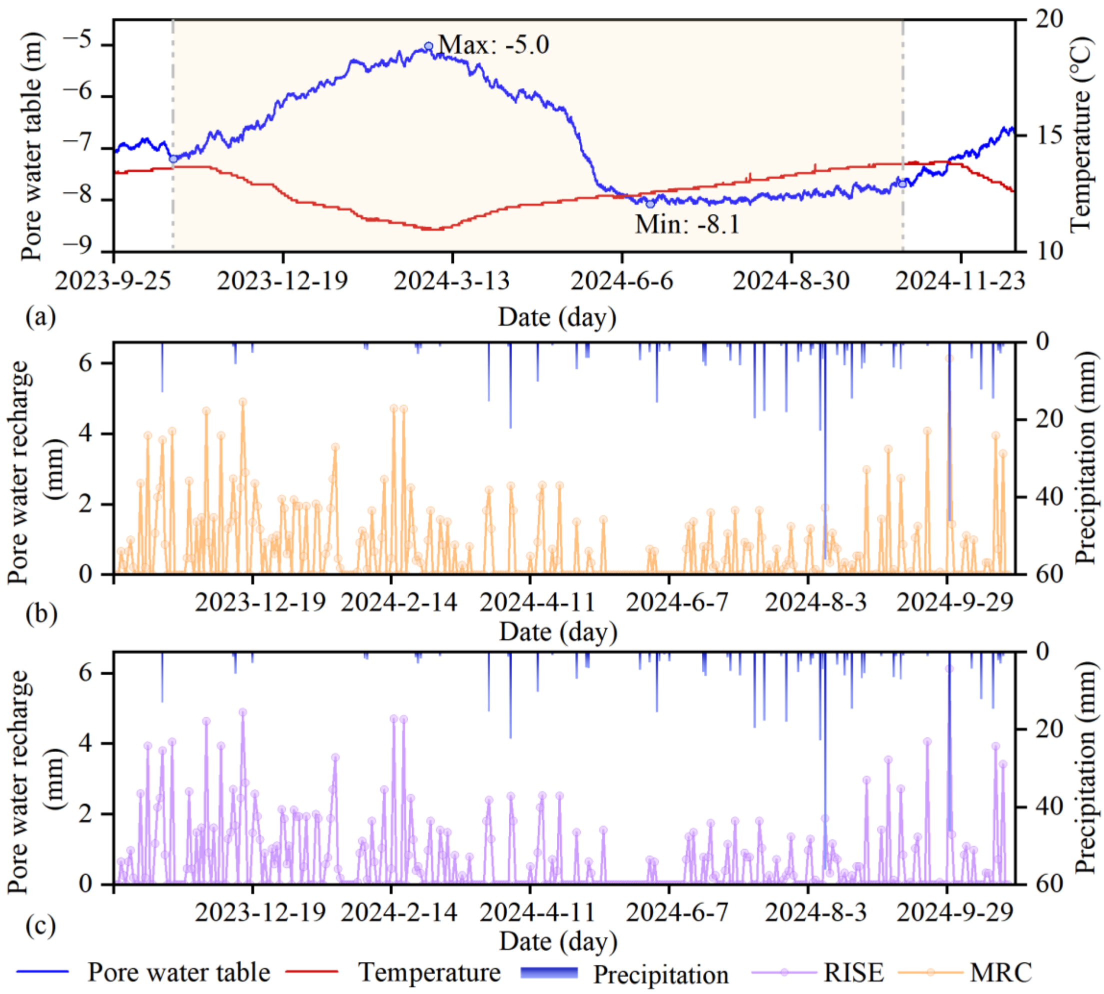
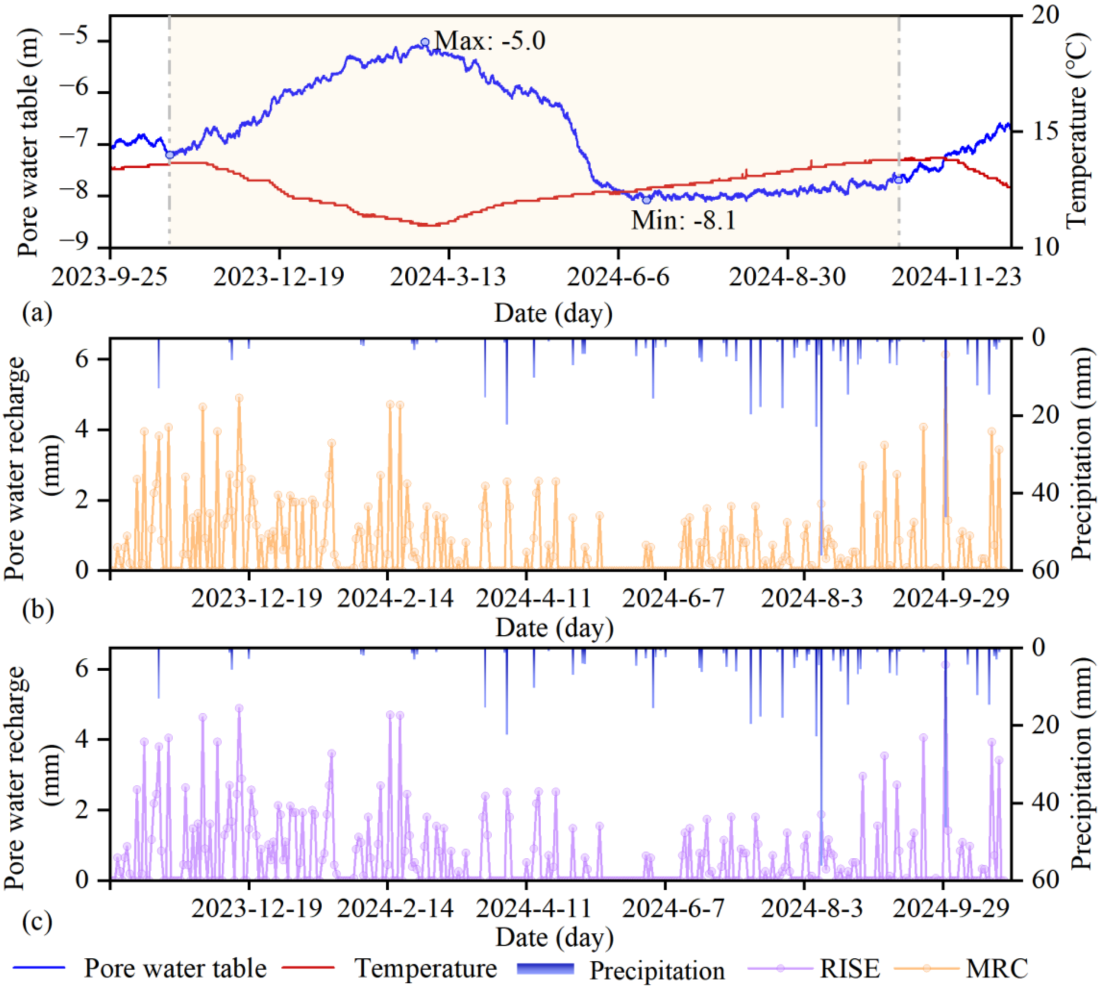


Fig. 10. Temporal dynamics of pore water table depth, temperature, precipitation, and recharge in the gully region of the Loess Plateau. (a) Daily time series of pore water table depth (blue line) and surface temperature (red line) from September 2023 to November 2024. The water table fluctuates seasonally, rising from ~−8.1 m in late summer to a maximum of ~−5.0 m in early spring (March 2024), indicating delayed infiltration and cool-season recharge. (b) Daily precipitation (blue bars) and modeled pore water recharge estimates using the MRC methods. (c) Daily precipitation (blue bars) and modeled pore water recharge estimates using the RISE methods. Most recharge events occur from October to April, even when rainfall is not especially high, while warm-season precipitation contributes little to recharge, likely due to increased evaporative losses and shallow soil retention. Together, these patterns suggest strong seasonal control on recharge processes, with effective infiltration primarily occurring during cooler, low-evaporation periods.

3. In Fig. 9b, the overlap of 'pore water recharge' and 'precipitation' affects the visibility of the recharge results. It is recommended to display precipitation separately or on the upper axis of the

figure.

Response: In the original manuscript, we placed the precipitation and pore water recharge data on the same axis to better illustrate their synchronous relationship, which led to some visual overlap. Following your comment, we have moved the precipitation data to the upper axis of Fig. 9b (in the original manuscript, and now Fig. 10b in the revised manuscript), ensuring that the visibility of the recharge results is not obstructed. The specific revision is as follows:



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precipitation contributes little to recharge, likely due to increased evaporative losses and shallow soil retention. Together, these patterns suggest strong seasonal control on recharge processes, with effective infiltration primarily occurring during cooler, low-evaporation periods.