

Dear reviewers and editor,

Thank you so much for your constructive comments. Please check our responses to all your comments point by point (followed and marked in blue). Unless specified, all the line numbers in our responses refer to the line numbers of the TRACK CHANGES version of the manuscript.

Besides, the responses to the two reviewers, we also made the following updates to the manuscript:

1. We acknowledged the work of editorial board and reviewers in the acknowledgements (Lines 834-836).
2. We updated the author's affiliation (Lines 11-13) and "Financial support" (Lines 837-846).
3. We updated Figure 13 (Lines 654-656) to maintain consistency with the format used in the other figures. We have made minor language and grammar edits throughout to improve readability; these changes do not affect the scientific content.

RC1:

Line-by-line comments:

18: "aims to investigate"

Response#1:

Thanks for pointing that out. We revised it (Line 19).

23-24: "Scenarios are high, normal, low, and extremely low annual"

Response#2:

Thanks for the suggestion. We modified it into "...*four scenarios (wet, normal, dry and extremely dry conditions)*..." (Lines 24-26).

38: "a drought"

Response#3:

Thanks for pointing that out. We revised it (Line 40 & 807).

41: delete "merely"

Response#4:

Thanks for the suggestion. We deleted it (Line 43 & 810).

Line 57: "Heavy rainstorms and severe droughts being the predominant..." -> "Heavy rainstorms and severe droughts, the predominant..."

Response#5:

Thanks for pointing that out. We rephrased this sentence as "*As predominant extreme climate events worldwide, heavy rainstorms and severe droughts share a common characteristic of rainfall variability*" (Lines 59-61).

Line 87: "detected higher soil N surplus ... and decreased the terrestrial N export" -> "detected higher soil N surplus ... and a decrease in terrestrial N export".

Response#6:

Thanks for pointing that out. We modified it (Line 92).

Line 94: "They seem opposite conclusions" -> "These appear to be opposite conclusions".

Response#7:

Thanks for the suggestion. We modified this sentence accordingly (Lines 101-102).

139: "The types of land use in the catchment do not generally convert until the economic and ecological goals vary between years" -> "The land use types generally remain stable unless economic and ecological goals change"

Response#8:

Thanks for the suggestion. We corrected it accordingly (Lines 149-152).

146: "is considered as the unique exit" -> "is considered the sole exit"

Response#9:

Thanks for the suggestion. We revised it accordingly (Line 155-156).

244: “The transformation and transport of nitrogen in the underground area are tracked…” -> “The transformation and transport of nitrogen in the subsurface are tracked…”

Response#10:

Thanks for the suggestion. We modified it accordingly (Line 257).

374: Consider providing values here to put the qualitative scenarios in context. For example, what was the total rainfall in each scenario and how does that value compare to rainfall amounts in historical records?

Response#11:

Thanks for this suggestion. We added key information about historical meteorological data and rephased this sentence as “*To represent contrasting hydroclimatic conditions, three years were selected from the 1997–2022 record (mean 607.9 mm; range 408.2–916.3 mm): the wet year (2007, $P = 916.3$ mm), the normal year (2008, $P = 588.7$ mm), and the dry year (2018, $P = 444.1$ mm);*” (Lines 370-374)

437: Figure 3 – y axis labels are ambiguously positioned. Which bars go with which label?

Response#12:

Thanks for pointing that out. We modified the figure, as shown in Figure 3 (Lines 454-455).

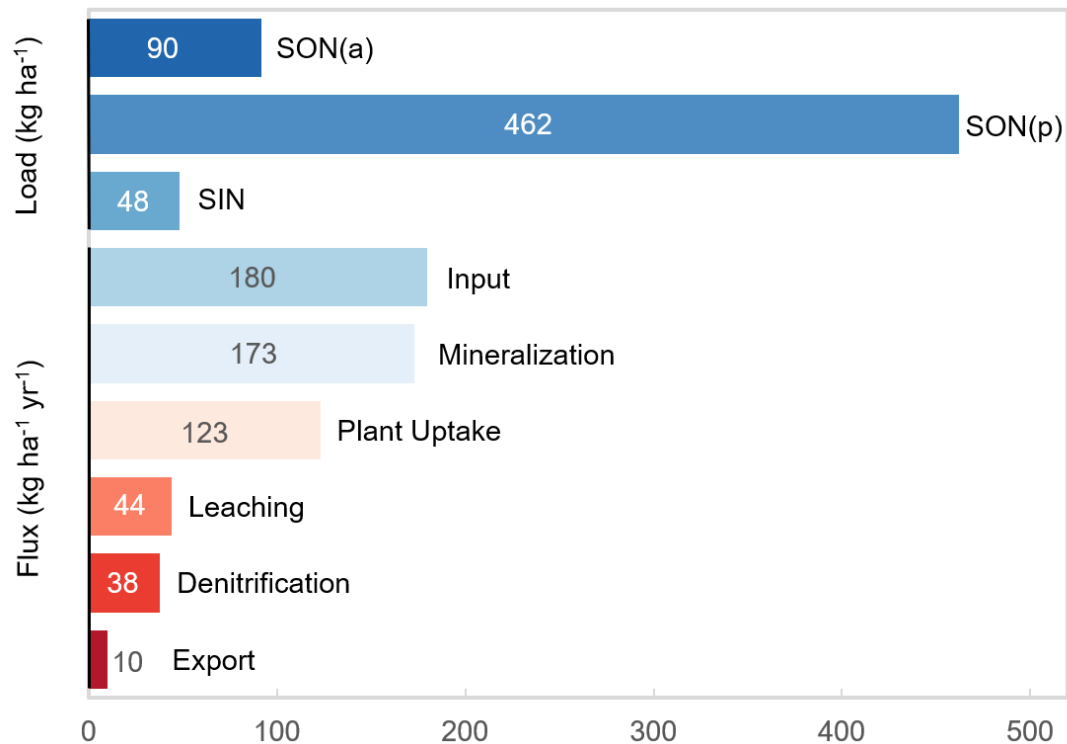


Figure 3. The simulated 14-year N mass balance in the entire catchment.

448: “transforms” -> “shifts”

Response#13:

Thanks for the suggestion. We modified it accordingly (Line 469).

457: “the transformation of SON is not subject to vegetation state” -> “SON transformation is independent of vegetation state”.

Response#14:

Thanks for the suggestion. We modified it accordingly (Line 479).

473: Readers may be confused why denitrification would be greater during an extremely dry year with low soil moisture.

Response#15:

Thanks for pointing that out. Accumulated SIN caused by reduced plant uptake makes denitrification be greater during an extremely dry year with low soil moisture. Thus, the sentence was modified into “*Because of the accumulated SIN load (Figure 6c) that resulted from the lowest level of plant uptake, denitrification and leaching fluxes in*

EDY with low annual precipitation are still even larger than those of WY." (Lines 492-496).

555 - "In warm periods, enhanced average rainfall intensity increased actual evapotranspiration (ET) (Figure S2b1 and S2c1)," The description seems to imply a positive correlation, but figure S2b1 and S2c1 both show steep negative slopes.

Response#16:

Thanks for this question. Negative values indicate that water leaves the subsurface. Figure S2 was modified to display actual evapotranspiration as positive values for clarity.

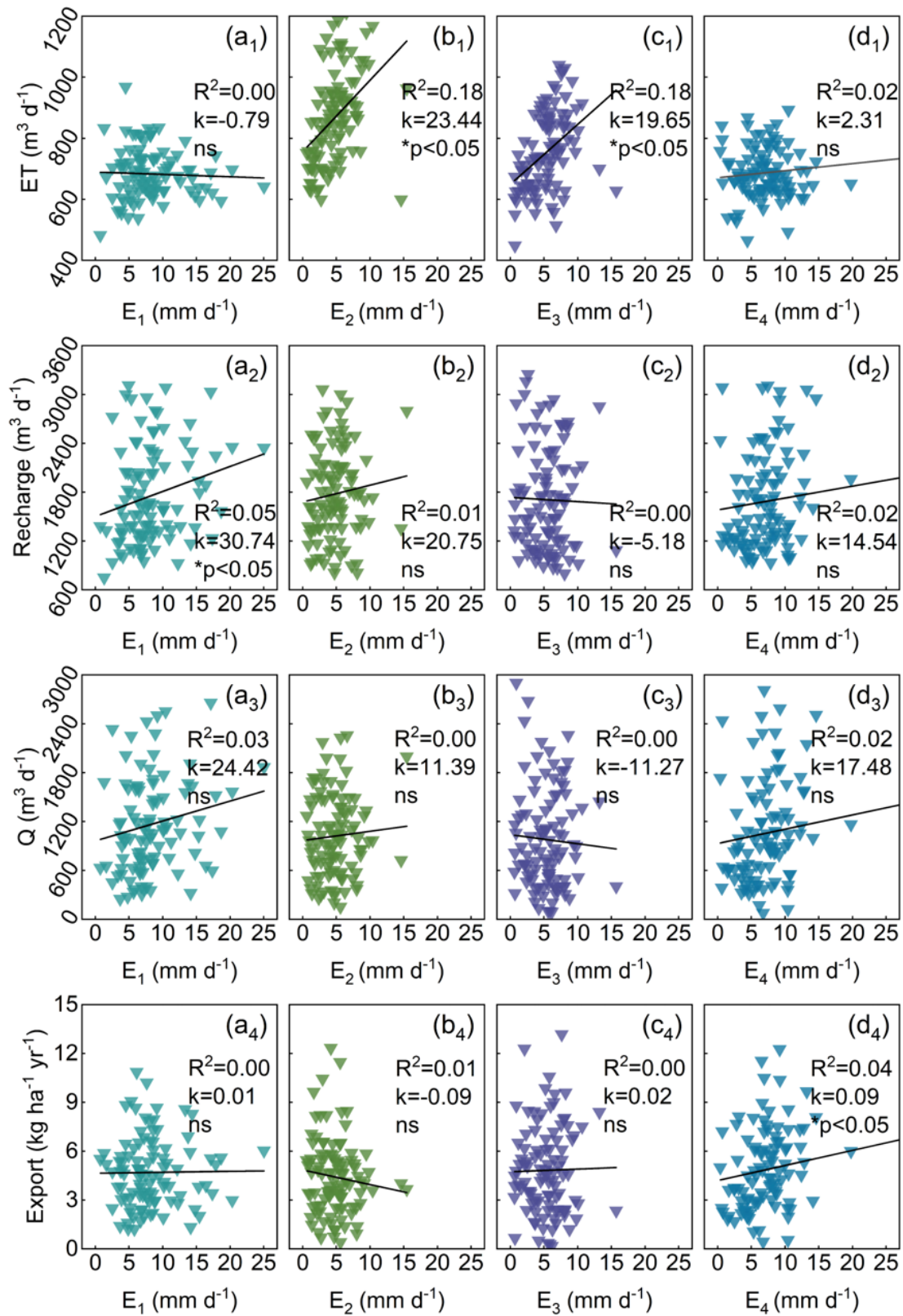


Figure S2. The responses of actual evapotranspiration (ET), recharge for groundwater, discharge (Q), and N export to the average rainfall intensity of the four seasons (E₁-E₄). The determination coefficients (R²) between E₁-E₄ and ET, recharge, Q, and export are listed. The sign and magnitude of the slopes (k) in these linear relationships denote the direction and the intensity of response of N dynamics to the variations in average rainfall intensity. Asterisks

indicate the significance of the regression slopes ($p < 0.05$); ns denotes non-significant relationships ($p \geq 0.05$).

557: “both recharge and discharge increased during the second season (Figure S2b2 and S2b3).” The description seems to imply a positive correlation. On plots S2b2 and S2b3, R-squared values are 0.01 and 0.00, and there are no discernable trends in the data points.

Response#17:

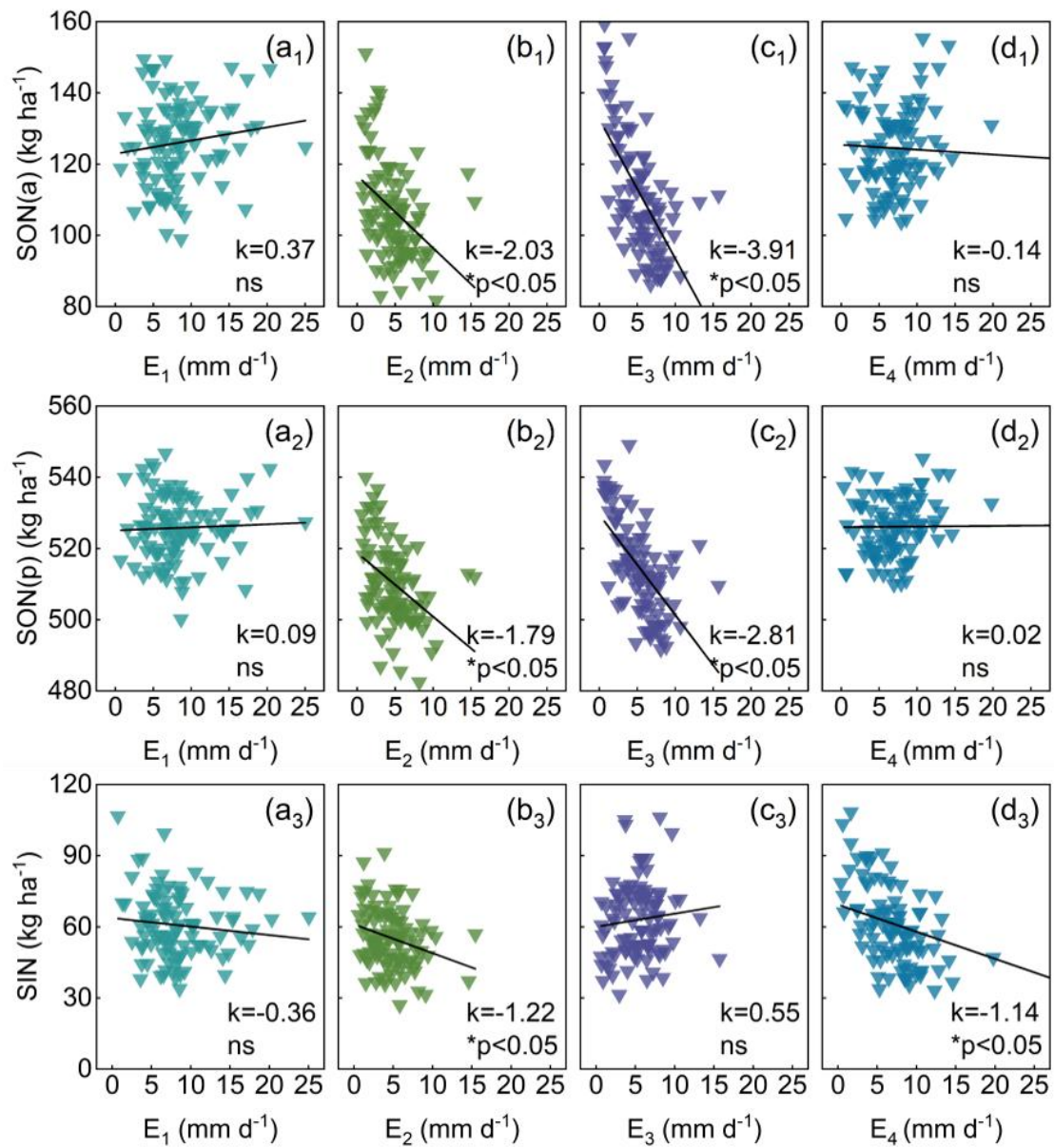
Thanks for pointing that out. After remarking the significance of linear regressions (in the next reply), we replaced the inaccurate description as “*In warm periods, enhanced average rainfall intensity increased actual evapotranspiration (ET) (Figure S2b₁ and S2c₁). The linear relationships between seasonal average rainfall intensity and each of recharge, Q , N export, and C_Q are weak, with low R^2 and small slope (k) values. Although several regressions reach statistical significance ($p < 0.05$), their effects are minor (Figure 11b₇, S2a₂, and S2d₄).*” (Lines 583-591). In addition, we modified the related description about denitrification into “*Warmer temperatures and enhanced moisture during the growing season promoted vigorous nutrient absorption by vegetation (Figure 11b₅ and 11c₅). In addition, soil denitrification increased markedly during the third season as average rainfall intensity increased (Figure 11c₆), which was due to favorable microbial conditions. In the fourth season, soil denitrification decreased slightly with increasing average rainfall intensity (Figure 11d₆), which was attributed to low temperatures and decreased SIN loads (Figure 11d₃).*” (Lines 576-583). The related discussion was also revised “*However, denitrification is dependent on microbial conditions as well. Leaching is additionally influenced by soil saturation and groundwater velocity (Equation 3 and 7). As a result, no significant linear relationship exists between mean rainfall intensity and leaching. It is noteworthy that high-intensity precipitation events with short durations and substantial surface runoff rarely reach the water table, thereby exerting minimal effects on recharge, discharge, and N export (a component of leaching flux) (Figure S2, Supporting Information). Therefore, C_Q shows weak and non-significant responses to extreme precipitation.*” (Lines 732-742).

563: Consider including information about which of the trends are statistically significant.

Response#18:

Thanks for this suggestion. We remarked the significance of linear regressions in Figure 11, 12, and S2. The method and results of linear regressions were added into the related

paragraphs (Lines 408-412, 527-528, 533-534, 549-551, 568-569, 615-617).



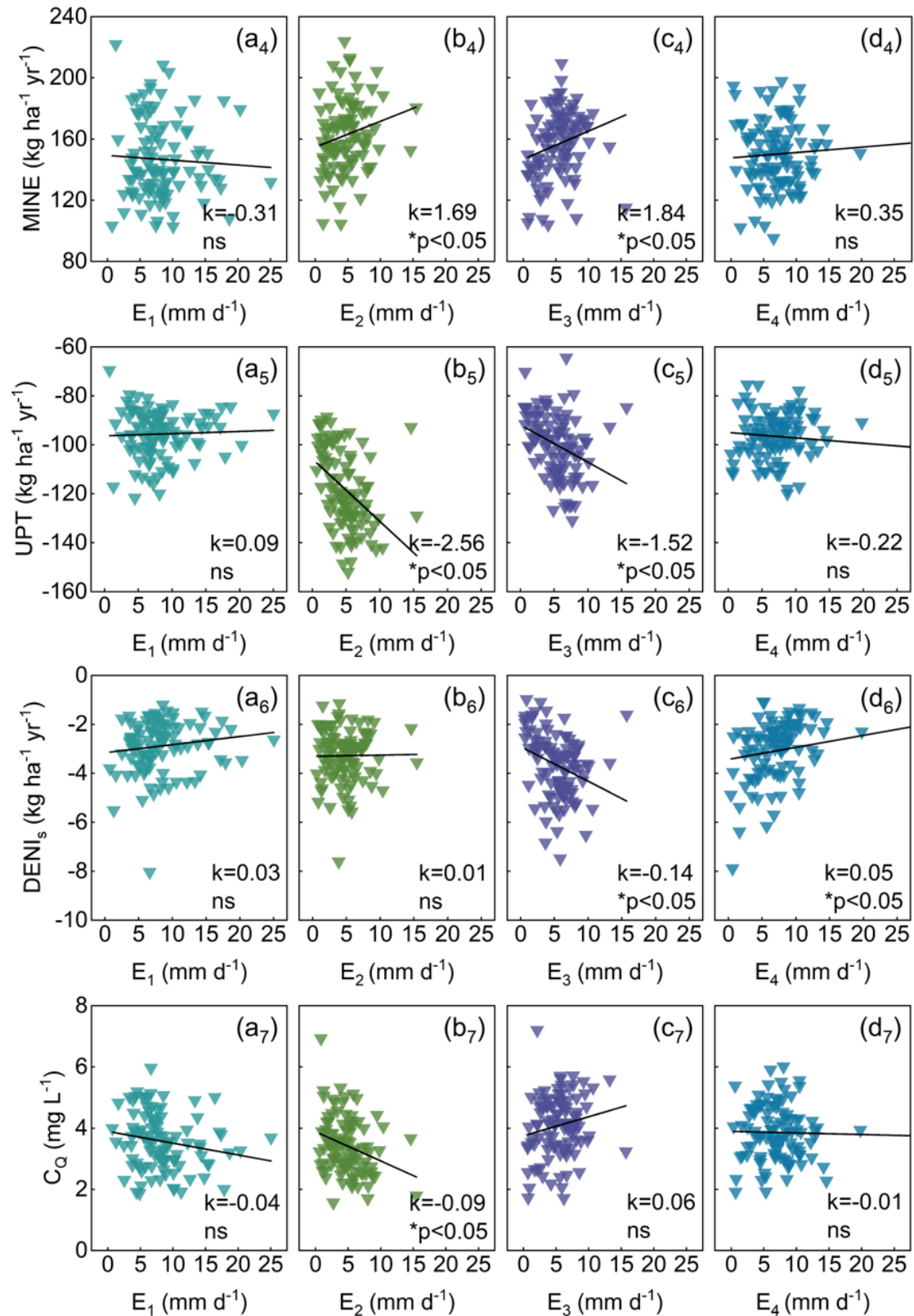


Figure 11. The responses of N loads, mineralization, plant uptake, and denitrification (in soil) fluxes, as well as in-stream nitrate concentration (C_Q) to the average rainfall intensity of the four seasons (E_1 - E_4). The sign and magnitude of the slopes (k) in these linear relationships denote the direction and intensity of the response of N dynamics to the variations in average rainfall intensity, respectively. Asterisks indicate the significance of the regression slopes ($p <$

0.05); ns denotes non-significant relationships ($p \geq 0.05$).

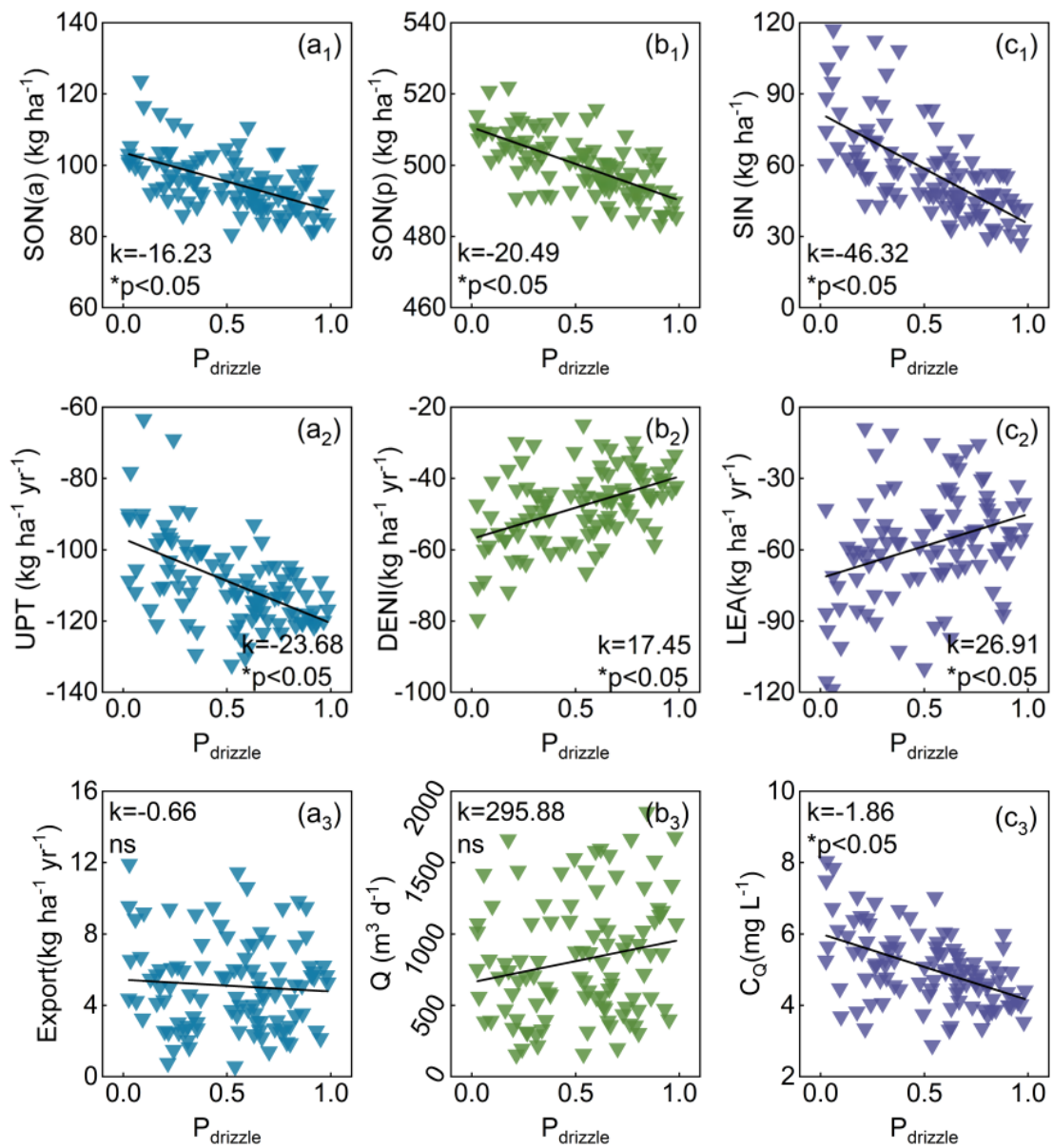


Figure 12. The responses of N loads, fluxes, discharge (Q) and in-stream nitrate concentration (C_Q) to the probability of drizzle events (P_{drizzle}). The sign and magnitude of the slopes (k) in these linear relationships denote the direction and intensity of the response of N dynamics to the probability of drizzle events (P_{drizzle}), respectively. Asterisks indicate the significance of the regression slopes ($p < 0.05$); ns denotes non-significant relationships ($p \geq 0.05$).

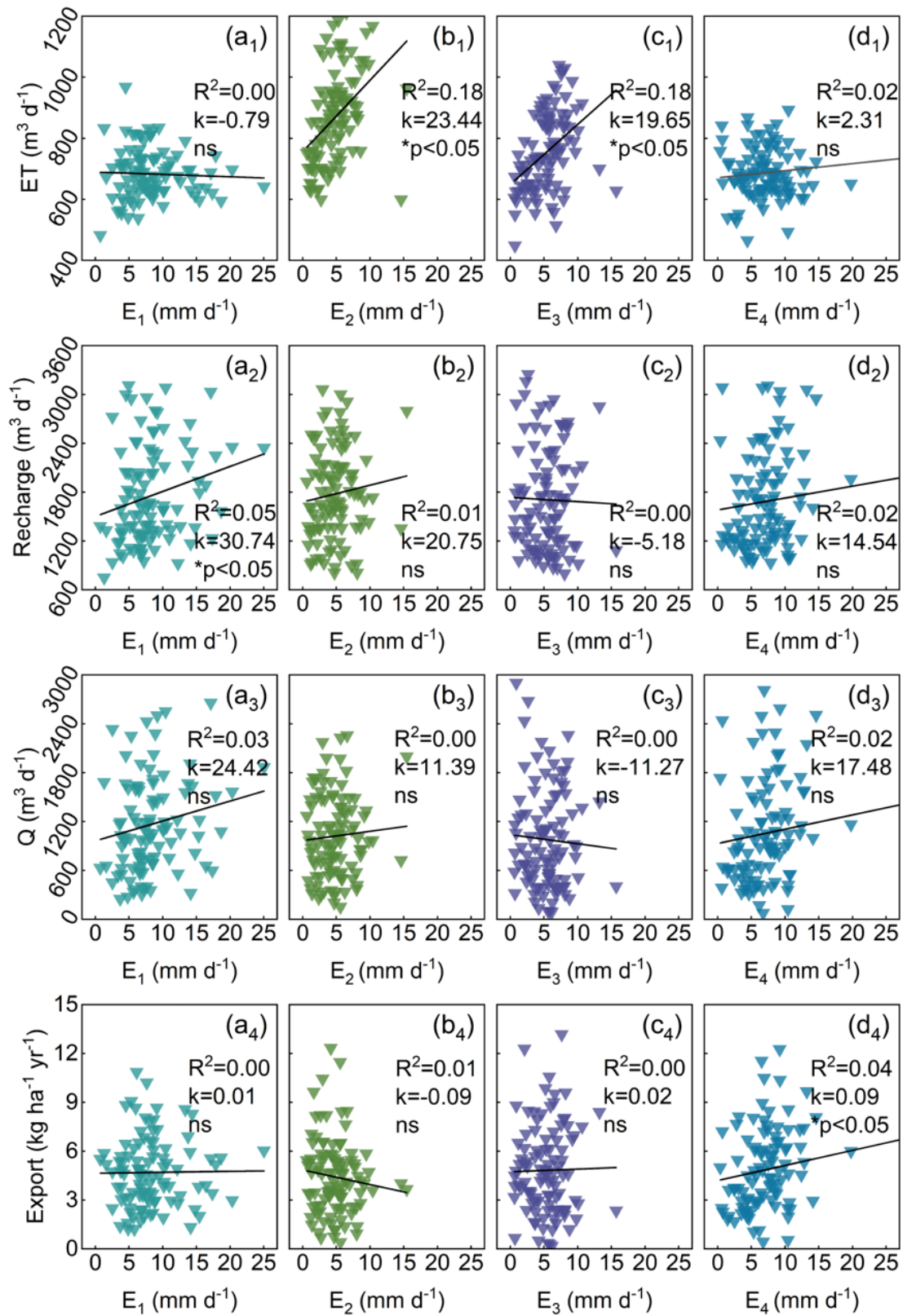


Figure S2. The responses of actual evapotranspiration (ET), recharge for groundwater, discharge (Q), and N export to the average rainfall intensity of the four seasons (E_1 - E_4). The determination coefficients (R^2) between E_1 - E_4 and ET, recharge, Q , and export are listed. The sign and magnitude of the slopes (k) in these linear relationships denote the direction and the intensity of response of N dynamics to the variations in average rainfall intensity. Asterisks

indicate the significance of the regression slopes ($p < 0.05$); ns denotes non-significant relationships ($p \geq 0.05$).

642: “induce prominent changes”

Response#19:

Thanks for the suggestion. We deleted “the” accordingly (Line 681).

677: “rarely propagate to the groundwater zone, minimally affecting discharge and nitrate export” -> “rarely reach the water table and thus minimally affect discharge and nitrate export”.

Response#20:

Thanks for the suggestion. The sentence was modified into “*It is noteworthy that high-intensity precipitation events with short durations and substantial surface runoff rarely propagate to reach the groundwater zone, thereby exerting, minimally affecting recharge, discharge, and nitrate N export (a component of leaching flux) (Figure S2, Supporting Information).*” (Lines 716-720).

688: “More discharge yielded in extreme dry-wet patterns than in continuously humid conditions” -> “Extreme dry-wet patterns yielded more discharge than continuously humid conditions”.

Response#21:

Thanks for the suggestion. This sentence and the next have been removed based on the context of the surrounding text (Lines 730-733).

705: “miscalculations”

Response#22:

Thanks for pointing that out. We modified it (Line 750).

709: delete “nonetheless”

Response#23:

Thanks for the suggestion. We deleted it (Line 753).

729: “Abundant microorganisms and animals engage in extensive activities, and massive organic and inorganic matter undergoes biochemical reactions …” -> “Microorganisms and soil fauna are highly active, and soil organic and inorganic matter undergo continual biochemical reactions…”.

Response#24:

Thanks for the suggestion. We modified it accordingly (Line 772-775).

737: “salt clusters” -> “salt accumulation”

Response#25:

Thanks for the suggestion. We modified it accordingly (Line 782).

751: delete “nonetheless”

Response#26:

Thanks for the suggestion. We deleted it (Line 29 & 797).

RC2#:

line 25 remove interannual

Response#1:

Thanks for this suggestion. We prefer to retain “inter-annual” (Line 27), which corresponds to “intra-annual” (Line 34). They denote the timescales of experimental rainfall variability.

line 29-30 of course, vegetation plays a vital role on N dynamics! I would rephrase as “vegetation response to extreme droughts will be the main controller of N fluxes

response to these extreme climatic events"

Response#2:

Thanks for pointing that out. We modified the sentence into “*vegetation plays a vital role in the response of N dynamics to extreme droughts*” (Line 31-32 & 799-800).

line 57-59 change for "heavy rainstorms and severe droughts are the predominant extreme climate events around the globe and are associated with change in rainfall variability "

Response#3:

Thanks for pointing that out. We rephrased this sentence as “*As predominant extreme climate events worldwide, heavy rainstorms and severe droughts share a common characteristic of rainfall variability*” (Lines 59-61).

line 67-68 : "On the opposite, severe droughts driven by precipitation deficits occur during several months and potentially years and it takes 1-2 years for hydrological components to recover"

Response#4:

Thanks for your suggestion. The sentence was modified into “*Different from heavy rainstorms, severe droughts driven by precipitation deficits occur during several months and potentially years [Otkin et al., 2018], from which it takes 1-2 years for hydrological components to recover [Hanel et al., 2018].*” (Lines 70-73)

line 88 : remove "the" terrestrial

Response#5:

Thanks for pointing that out. We deleted it (Line 92).

line 101-106 : the framing of knowledge gap could be improved here: I think that the scope of your study is to move beyond the case study shedding light on the effects of rainfall variability on N dynamics in a more systematic way and investigating the underlying mechanisms using a synthetic experimental study

Response#6:

Thanks for the suggestion. The framing of knowledge gap was rephrased as “*...Zhou et al. [2022] detected higher soil N surplus (total N input with the crop/plant uptake subtracted) and a decrease in terrestrial N export in agricultural areas located in*

Central Germany during the drought years (2015-2018). The same phenomenon reported in the Nitrate Report 2020 of the Netherlands (RIVM, 2021) indicates that more N was retained in the soil during the drought period compared to the pre-drought period. Notably, the 2018–2019 (consecutive) drought triggered unprecedented tree mortality across multiple species in Central European forests, accompanied by unexpectedly persistent drought legacy effects [Schuldt et al., 2020], from which Winter et al. [2023] drew the conclusion that severe multi-year droughts can reduce the nitrogen (N) retention capacity of catchments. These appear to be opposite conclusions, which can be attributed to different investigation timescales. The former study compared N export between drought years and the pre-drought period. The latter considered the subsequent rewetting period, when most nitrogen accumulated during the drought left the catchment. Leitner et al. [2020] also found that in the year after a summer drought, NO_3^- leaching via soil water seepage was significantly elevated compared to the long-term mean in a temperate mixed forest on karst, which was investigated in wetland-influenced catchments as well [Watmough et al., 2004]. These studies demonstrate that rainfall variability profoundly affects N dynamics at both inter-annual and intra-annual timescales. Therefore, it is imperative to shed light on the impact of rainfall variability on water quality in terms of N dynamics.

To fill the gap, the present study explored the impact of rainfall variability on N dynamics and its potential influence on water quality across inter-annual and intra-annual timescales.” (Lines 88-116).

line 121: specific parameters of rainfall distribution were used.

Response#7:

Thanks for your suggestion. We modified the sentence into “...rainfall time series generated by separately altering specific rainfall-generator parameters substitute for the rainfall data in the simulation period to drive the flow and nitrogen transport models.” (Lines 130-133).

lines 716-725 Related to my question on plant processes, another point is that in a very dry year, it is also very likely that farmers will modify their fertilization. Nevertheless the input is constant here in the model isn't it?

Response#8:

Thanks for the insightful comment. We agree that farmers may adapt fertilization in very dry years. Due to limited information on farm behavior and model limitation,

considering the adaptive farm management is outside the scope of this work. The present study is designed to explore the effects of rainfall variability on nitrogen (N) dynamics. To achieve the attribution, we intentionally held temporally constant fertilization rate across scenarios and represented extreme drought by very low annual precipitation and reduced plant uptake potential due to vegetation dieback. This design avoids confounding management decisions with hydrometeorological drivers and allows us to focus on mechanism identification (plant uptake, denitrification, and leaching) under rainfall variability. We have clarified this assumption in the Methods “*To isolate the causal effects of rainfall variability on N dynamics, the time-invariant fertilization rate was used across all scenarios*” (Lines 396-398). We believe this scoping choice is appropriate for the study’s objective.