Dear Prof. Markus Hrachowitz,

We have substantially revised our manuscript according to the editor and reviewers' insightful comments and suggestions. All the comments are addressed in the new version of the manuscript, **sections 4.3 and 4.4 of the Results part have been rewritten**, **two figures (Figure 13 and Figure 15), several new references and discussions have been added to enrich the study.** Below is the attached point-by-point explanation of our correspondence for each comment or suggestion by the editor and reviewers. All additional and changed parts of the text (except some minor changes) are marked in BLUE for easy review.

We sincerely hope you and the reviewers will find the revised version of the manuscript much more comprehensive and robust. All the authors have reviewed the manuscript and agree to the submission of the manuscript. We look forward to hearing from you.

Thank you for your time and efforts on our manuscript again.

Sincerely yours,

August 20th, 2022

Corresponding author

Prof. Shenglian Guo

State Key Laboratory of Water Resources & Hydropower Engineering Science

Wuhan University, Wuhan, Hubei Province, 430072, P. R. China

E-mail: slguo@whu.edu.cn

Reply to the editor's comments

Comments to the author:
Dear authors,

two reviewers have provided detailed lists of excellent comments on the revised version of your manuscript. While both of them agree that the manuscript has improved, they also flag a suite of major issues that remain to be resolved before the manuscript can be considered for publication.
I strongly encourage you to address these issues in detail and to adequately incorporate the reviewer suggestions in another round of revisions, which will be sent out for a further round of reviews.
I am looking forward to the revised version of your manuscript.
Best regards,
Markus Hrachowitz

Reply: We really appreciate the comments proposed by the Editor. A point-to-point response has been made to address all comments raised by both reviewers.

Reply to the reviewers' comments

Reviewer # 1

A1. I thank the authors' replies. But I regret that the authors still insist on the usage of the "new" term "catchment water storage capacity" in the title, which is not specific, and does not make clear sense. Moreover, the author mentioned the "catchment water storage capacity" shall include groundwater, which is a huge reservoir, but they did not take groundwater storage capacity into account in the model. I don't think the hydrological science community shall accept this new term. Out of prudence, I download the full text of all the 5 publications, listed by the authors to support their statement. I cannot find "catchment water storage capacity" in (McNamara et al., 2011; Perrin et al., 2003; Saft et al., 2015; Westra et al., 2014). The term "catchment water storage capacity" only occurred in Pan et al., 2020, which is from the authors' group. Furthermore, I search the "catchment water storage capacity" on internet, and did not find any usage of this term in other serious peer-reviewed papers.

Reply: Thanks for your professional comments.

(1) The term "catchment water storage capacity" was reviewed and summarized from the following sentences of the listed references:

(a) "***The volume of water stored within a catchment****, and its partitioning among groundwater, soil moisture, snowpack, vegetation, and surface water are the variables that ultimately characterize the state of the hydrologic system*." (the first sentence in the Abstract part of McNamara et al. (2011)),

(b) "*Accordingly,* ***catchment water storage*** *may serve as insightful metrics for catchment comparison. Unfortunately, very few studies report storage measures. Recent work has demonstrated, or perhaps revived, a general interest in* ***catchment water storage*** *(Spence et al., 2007, 2010; Kirchner, 2009; Soulsby et al., 2009).*"(the sixth and seventh sentences in the Introduction part of McNamara et al. (2011)).

(c) "*x1 (mm) is the* ***maximum capacity*** *of the SMA store.*" (the first sentence below Equation (3) in section 2.2 of Perrin et al (2003)). The term "SMA" refers to the soil moisture accounting model.

(d) "For example, we use a sinusoidal function to represent seasonal changes in the **catchment storage capacity**." (the third sentence in section 2.2 of Westra et al (2014)).

Based on these mentioned previous studies, we have combined the meaning of terms "catchment water storage" and "catchment storage capacity", and used the term "catchment water storage capacity" in our study.

(2) As the Reviewer point out that the term "catchment water storage capacity" is not specific, and does not make clear sense. After a heated discussion within the group,

we decide to follow the suggestion proposed by the Reviewer and used the term "root zone storage capacity (i.e., active catchment water storage capacity (ACWSC)" to replace the term "catchment water storage capacity" in the revised manuscript.

A2. I did not see the clear track change of the language improvement. Maybe the authors did not highlight what they changed?

Reply: Thanks for your comments. This is because we didn't mark the revision of grammar and language in the last round of revision.

Reviewer # 2

I commend the authors for their effort in improving the manuscript and for providing well-structured responses. However, I still have several major concerns:

B1. Line 74-77: Why is catchment water storage capacity (CWSC) referred to as 'unregulated and unimpaired'?

Reply: Thanks for the comments. The phrase "unregulated and unimpaired" was once used to constrain the scope of research aims, and reduce the potential effects of serious human interventions. For clarification, the phrase 'unregulated and unimpaired' has been deleted in the revised manuscript.

B2. Line 405-407: The authors report that, on average, catchments that experienced an increase in storage have high retention time, but the catchments that show a decrease in storage have low retention time. However, no still description of forest or soil characteristics/topographical differences that lead to these differences are mentioned. Also, are there any exceptions to this? Based on the statement above, it is hard to infer the catchment dynamics and whether these trends are exclusive to the analysed Australian catchments.

Reply: Thanks for your comments.

(1) In section 4.2, only the response times of different groups of catchments with significant increase/ decrease in regression parameters α and δ were shown, the description of forest or soil characteristics/topographical differences that lead to these differences were mentioned in Section 4.4. Please refer to lines 584-621 in the revised manuscript.
(2) Since we are comparing the mean and median values taken for different groups, there are exceptions to this, such as the response time of 92.2 days for the catchment number # 217002 in the significantly increasing group in amplitude α, and 122.6 days for the catchment number # 203005 in the significantly decreasing group in

amplitude α.

(3) We agree with the reviewer that it is hard to infer the catchment dynamics and whether these trends are exclusive to the analyzed Australian catchments. As in this study, there are 83 catchments identified with a significantly increased change of the amplitude α, while only 4 catchments were found with a significantly decreased change in the amplitude α. It is not clear whether the difference between the groups of catchments with significant increase/decrease change of the amplitude α is real or just sampling fluctuations.

B3. Line 410-411: Similarly, catchments with increased variation intervals (which I believe refers to variance) have a high response time. This can easily be debated without any indication of catchment characteristics.

Reply: Thanks for your comments.

(1) As our response to B2: The analysis of catchment characteristics under different groups is presented in section 4.4 of the revised manuscript. In addition, in this study, there are 83 catchments identified with a significantly increased change of the amplitude α, while only 4 catchments were found with a significantly decreased change in the amplitude α. It is not clear whether the difference between the groups of catchments with significant increase/decrease change of the amplitude α is real or just sampling fluctuations.

(2) The sentence has been modified as: 'According to the results shown in **Table 6**, a significant difference was identified in the length of the response time between two sets of catchments with a significant increase and decrease in amplitude α. However, it is not clear whether the difference between the groups of catchments with significant increase/decrease change of the amplitude α is real or just sampling fluctuations. '

B4. Also, same as my comment during the previous revision: Line 440-442 '….catchments with small areas, low elevations, small slope ranges, large forest coverage, and high AWHC of soil may change more significantly than catchments with opposite characteristics.' Although the authors, in their response, justified this claim, they have not included the same in the manuscript. They could briefly put something like - 'large forest cover in a small area will require considerably large (partitioning of) soil moisture storage. That is why these catchments are highly vulnerable under prolonged droughts due to competitiveness for moisture uptake than catchments with low forest coverage and large area.' The authors should state something similar for the statements/comments (mentioned above) at appropriate places in the manuscript.

Reply: Thanks for the suggestions. The relevant explanation has been added to the text in lines 472-480 in the revised manuscript as follows:

'Generally, small areas of large forest cover will require considerable (partitioning of) soil water storage. After experiencing persistent meteorological drought, the pressure on water resources in the catchment increased and tree cover was lost in large quantities due to withering. Canopy retention and uptake by the forest is an important part of ACWSC, and the dieback of trees in the forest may result in a significant change in ACWSC (Adams et al., 2012). This is why catchments with small areas and large forest coverage are more vulnerable under prolonged drought due to competition for moisture uptake than catchments with low forest cover and large areas.'

B5. Clustering catchment (as in Line 440-442) without proper justification opens the manuscript to more concerns. E.g., how will CWSC change for catchments with large areas and extensive forest cover? Would it be the same as before if all the other variables (slope, topsoil, etc.) remained the same? Is there a reason a specific cluster is discussed? Are there no catchments with large areas and extensive forest cover?

Reply: Thanks for your comments.

(1) The significance level of $|\pm 20\%|$ in amplitude α was used to cluster catchments into $g_{\alpha}(S)$ and $g_{\alpha}(NS)$ groups. It should be mentioned that the determination of the significance level of $|\pm 20\%|$ followed Pan et al (2020), which was empirical but rigorous in distinguishing catchment groups with apparently different variations in amplitude α .

(2) Due to the limitation of the number of samples, no catchment in the studied region has been identified with a larger area meanwhile with a high forest coverage percentage. For example, only five catchments were identified within the $g_{\alpha}(NS)$ group, the catchment 410091 has the largest catchment area (2808km^2) within the group but its forest coverage percentage is only 0.21. Similar findings were identified in the $g_{\delta}(S)$ group, i.e., the ten catchments with the largest areas were totally different with the highest forest coverage percentage.

(3) Actually, our next research plan is to explore the potential variation patterns of the changing patterns of the model parameters in experimental catchments that were similar in most catchment characteristics except for the forest coverage percentage. However, we did not find such catchments in the studied region.

(4) The reason for dividing the catchments datasets into $g_{\alpha}(S)$ and $g_{\alpha}(NS)$ groups based on the significant degree in amplitude α was to compare the difference in catchment properties and climate inputs, and explore the potential

interrelated mechanisms.

B6. Section 4.3. 'Factors for shifts in the CWSC' and 4.4 'Factors for the response time of catchment', which I believe are critical to this manuscript, need to be improved considerably.

Reply: Thanks for the comments. Sections 4.3 and 4.4 have been rewritten in the revised manuscript according to your suggestion. Please refers to lines 414-621 in the revised manuscript.

B7. Line 506-508: The authors claim that response time positively correlates with mean elevation and AWHC of the topsoil, while negatively correlating with forest coverage (Fig. 13). But no justification on the dynamics is provided. Let's say under prolonged drought, vegetation gains access to groundwater resources, increasing response time (i.e., the time between the start of drought and change or change point in CWSC). How is that justified in the results presented by the authors.
Also, Fig. 10, 12, and 13 are overly complicated. Since we are not comparing or discussing the correlation between variables anywhere in the manuscript, it might be better to remove them. Only the first row of the figure is more than enough.

Reply: Thanks for the comments.

(1) Possible reasons and several references for the positive correlation between the response time with the AWHC of the topsoil and the mean elevation have been added in the revised manuscript as follows:

'The potential reasons for this finding may lie that the larger ACWSC indicated a higher ability of the soil to retain water and make it more sufficiently available for plant use, thus resulting in an increased response time in the catchment (Lawes et al., 2009; Leenaars et al., 2018). Meanwhile, the increased catchment elevation may promote changes in forest architecture (i.e., decreases in tree stature and stem diameter, trends in stem deformation, hard, thick, and smaller leaves) and enhance the dominant position of plants with less water assumption (Lenoir et al., 2008; Oke and Thompson., 2015), and thus relatively enlarge the response time. '

Please refer to lines 589-597 in the revised manuscript.

(2) We agree with the opinion that the groundwater acted as a cushion to maintain the surface runoff and promote the survival of the plants under drought events. However, the interactions between the surface water and groundwater would be gradually reduced because of the falling groundwater levels if the drought conditions persist for several years and even decades. Meanwhile, the persistent decline of the groundwater level and storage has been observed in catchments of Southeastern Australia (Leblanc et al., 2009). Thus, the increase in forest coverage

may enlarge the water demand and reduce the response time during a prolonged meteorological drought.

For further clarification, the sentences that justified the implication of forest have been modified as follows:

'In addition, the persistent decline of the groundwater level and storage has been observed in catchments of South-eastern Australia (Leblanc et al., 2009), resulting in the gradual reduction of the interactions between the surface water and groundwater (Van et al., 2013). Thus, the increased forest coverage of the catchment may result in larger water demand for the ecosystem (Adams et al., 2012), and thus caused a shorter response time of the ACWSC to the meteorological drought.'

Please refer to lines 597-603 in the revised manuscript.

(3) Fig. 10, 12, and 13 have been modified (the corresponding numbers of these figures are Fig.11, 12, and 14 in the revised manuscript), only the first rows of these figures are retained as required, which are shown as follows:

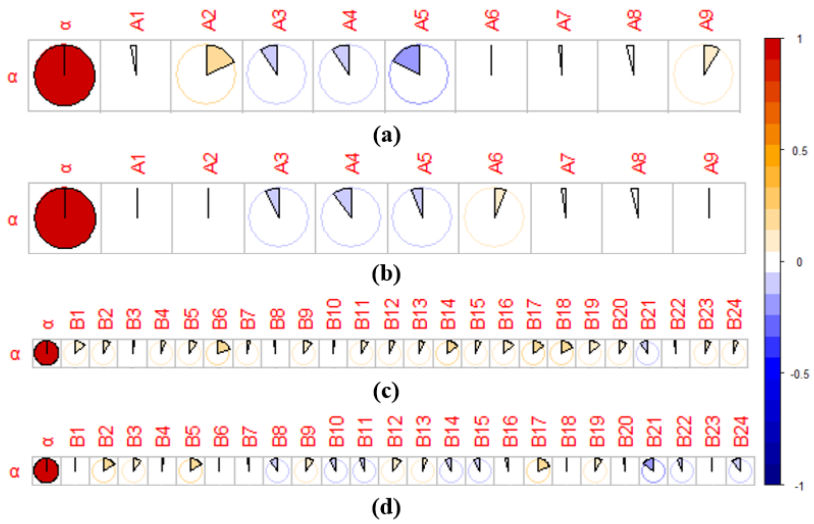


Fig.11. The Pearson correlation coefficient between the variation in the amplitude α with multiple catchments features and climate variables. (a) Correlation between the absolute variation of amplitude α and catchment features; (b) Correlation between the relative variation of amplitude α and catchment features; (c) Correlation between the absolute variation of amplitude α and absolute variation of climate variables; (d) Correlation between the relative variation of amplitude α and relative variation of climate variables.

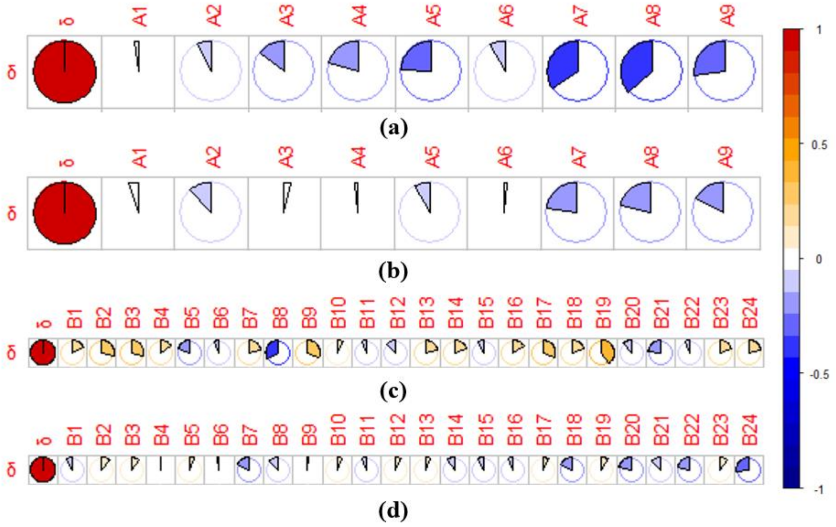


Fig.12. The Pearson correlation coefficient between the variation in the mean value δ with multiple catchment features and climate variables. (a) Correlation between the absolute variation of mean value δ and catchment features; (b) Correlation between the relative variation of mean value δ and catchment features; (c) Correlation between the absolute variation of mean value δ and absolute variation of climate variables; (d) Correlation between the relative variation of mean value δ and relative variation of climate variables.

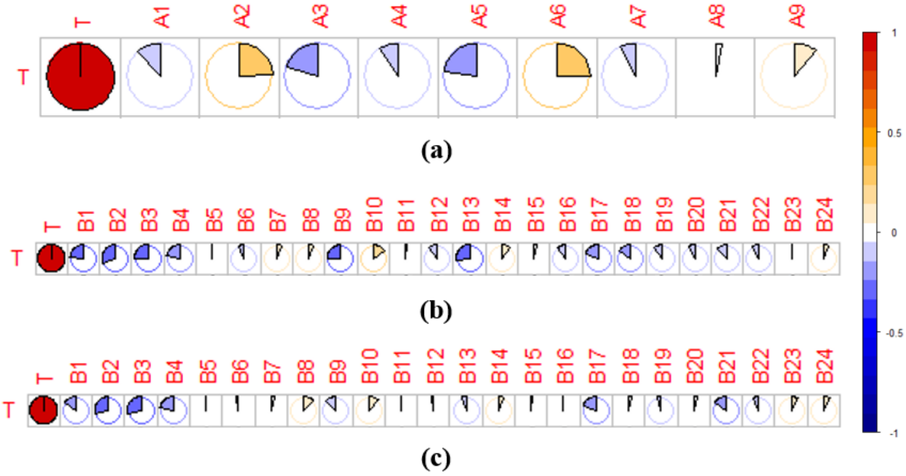


Fig.14. The Pearson correlation coefficient between the response time with catchment features and variation in climate variables before and after the change point. (a) Correlation between the response time and catchment features; (b) Correlation between the response time and absolute change of climate variables; (c) Correlation between the response time and relative change of climate variables.

Added references:

Lawes, R. A., Oliver, Y. M., Robertson, M. J.: Integrating the effects of climate and plant available soil water holding capacity on wheat yield, Field Crop. Res., 113(3),

297-305, 10.1016/j.fcr.2009.06.008, 2009.
Leenaars, J. G. B., Claessens, L., Heuvelink, G. B. M., et al. Mapping rootable depth and root zone plant-available water holding capacity of the soil of sub-Saharan Africa, Geoderma, 324, 18-36, 10.13140/RG.2.1.3950.9209, 2018.
Lenoir, J., Gégout, J. C., Marquet, P. A., de Ruffray, P., and Brisse, H.: A significant upward shift in plant species optimum elevation during the 20th century, Science, 320(5884), 1768-1771, 10.1016/j.idairyj.2006.12.007, 2008.
Oke, O. A., Thompson, K. A.: Distribution models for mountain plant species: the value of elevation, Ecol. Model., 301, 72-77, 10.1016/j.ecolmodel.2015.01.019, 2015.
Leblanc, M. J., Tregoning, P., Ramillien, G., Tweed, S. O., and Fakes, A.: Basin-scale, integrated observations of the early 21st century multiyear drought in southeast Australia, Water Resour. Res., 45, 10.1029/2008wr007333, 2009.
Van Lanen, H. A. J., Wanders, N., Tallaksen, L. M., and Van Loon, A. F.: Hydrological drought across the world: impact of climate and physical catchment structure, Hydrol. Earth Syst. Sc., 17, 1715-1732, 10.5194/hess-17-1715-2013, 2013.

B8. All my previous comments point to this: I am sure that the characteristics of the 92 catchments are not similar (as the authors have acknowledged in the manuscript). Therefore, it doesn't make sense to assume the catchments as one and look at their correlation as one (Fig. 10, 12, 13). Instead, fix some common variables (e.g., analyse catchments with similar elevation or forest cover), and then look for trends that highlight the causation between variables (say 'response time' and other catchment characteristics). This might help the authors build a consistent story about the catchment characteristic and associated dynamics. Furthermore, there are also some techniques which can do multi-variable clustering as well, if authors want to do that to find similarities between catchments. However, currently, what is proposed in the analysis and the manuscript are not so coherent.

Reply: Thank you.

(1) We agree with reviewer #2 that the studied 92 catchments were not similar in these catchment characteristics. However, they were spatially located in close proximity and within the region of Southeast Australia, spatially coherent catchments have been proved to have similarities in catchment characteristics in historical literature (Outin et al., 2008), e.g., the common meteorological drought event in those 92 catchments).

(2) The main purpose of this study is to explore the response of ACWSC to the meteorological drought and asymptotic climate variation, rather than to find the impact of dynamics in a single factor on the variation of the ACWSC.

(3) Due to the fact that (a) recent studies still cannot clarify completely the complex production and confluence mechanisms of the catchment, and (b) each hydrological model is a generation expression of the catchment runoff generation mechanisms, we much more focused on analyzing and reflecting

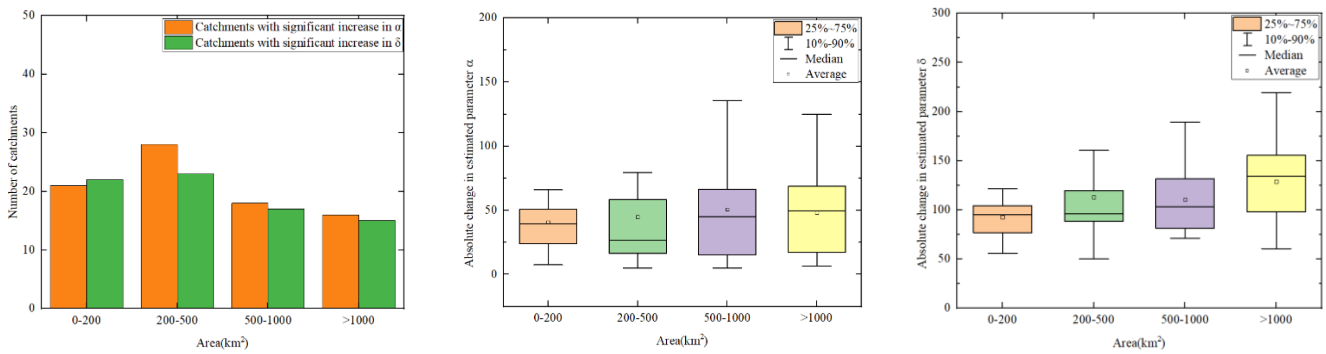
the statistical characteristics (include similarity and difference) of catchments with different change patterns, and exploring the potential reasons.

(4) In addition, due to the limitation of available datasets, we did not collect the necessary datasets for further analyzing the impact of a single feature on the potential variation of catchment dynamic. As a complement to point (3), this research may need a large sample of comparative catchments.

(5) The trend analysis based on the classification of certain variables (i.e., area, elevation, forest coverage, and soil characteristics) has been added to the modified manuscript. Please refer to lines 565-583 in section 4.3.3, which were also shown as follows:

'4.3.3 Trend analysis within the significant changed group

As our findings in **Table 5**, most of the studied catchments experienced a significantly increased variation after the change point, the $s_{\alpha}(IS)$ and $s_{\delta}(IS)$ subsets of catchments were further used as typical samples for the trend analysis between the variation in the ACWSC and certain characteristics. According to the results in sections 4.3.1 and 4.3.2, four catchment properties, i.e., catchment area, mean elevation, forest coverage, and soil characteristics, were adopted for the trend analysis. As illustrated in **Fig.13**, the absolute changes in α and δ both show an increasing trend with the increase in catchment area, the catchment group with the mean elevation within the internal of [300, 600] had the largest absolute change in both the amplitude α and mean value δ among all groups with different elevation interval, implying the potentially most suitable elevation range for the occurrence of the variation of ACWSC. Furthermore, the decreased variation of the estimated value of α and δ has been identified along with the increase in the forest coverage of catchments. In addition, **Fig.13** indicated that the changes in α and δ were both negatively associated with the increase in forest coverage percentage of the catchment, implying the positive contribution of high forest coverage to the potential change in the ACWSC during the meteorological drought. Similar relationship was observed in changes of δ with the AWHC subsoil.'



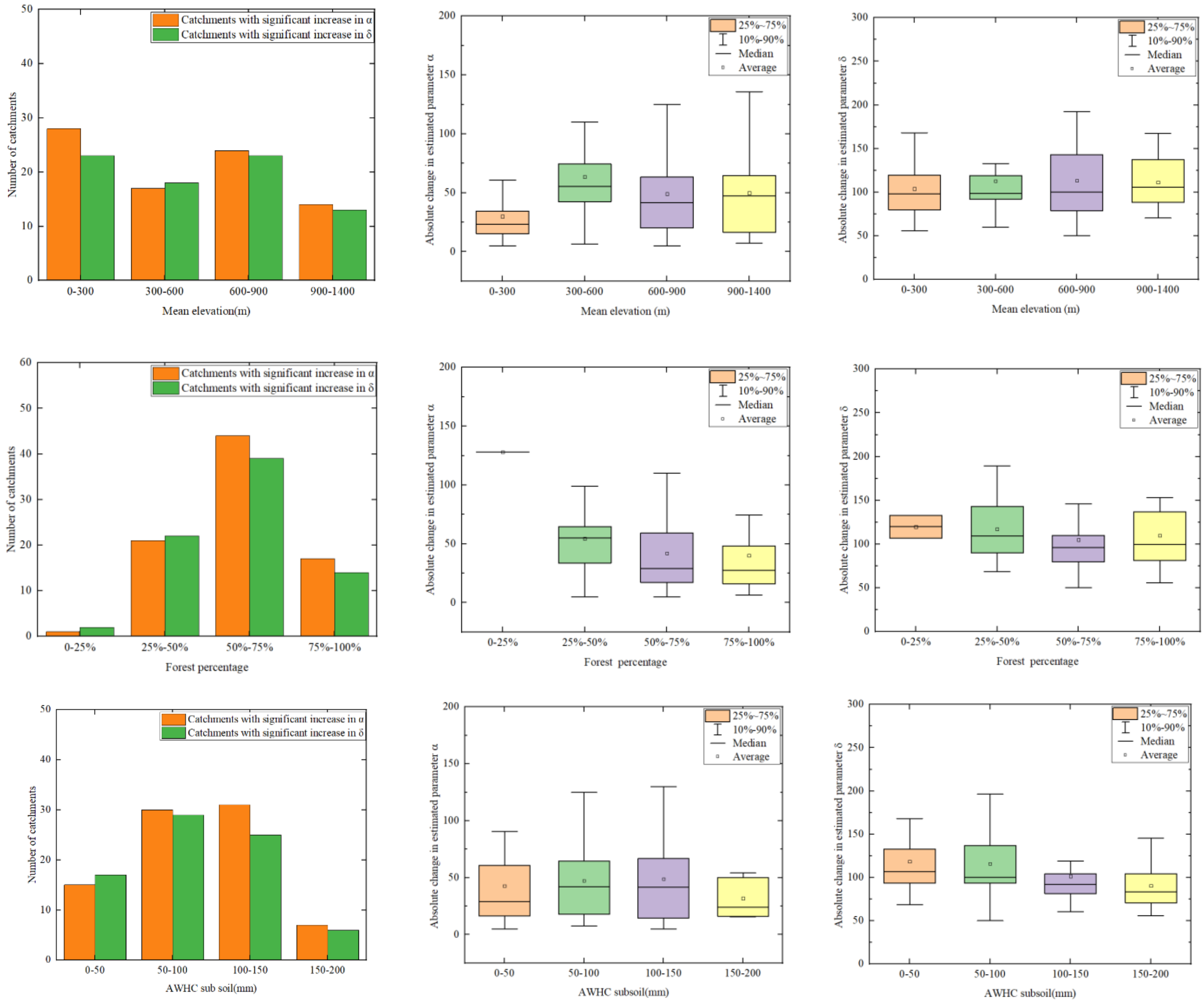


Fig.13. Trend analysis between the variation in the ACWSC and catchment properties.

B9. Authors suggest that (Line 543-546) under prolonged droughts, the hydraulic connection between ground and surface water would weaken, resulting in more voids in the soil and an increase in the CWSC. However, earlier in the paragraph, the authors also mentioned that (Line 539-540) the loam and silt loam found in the study area can maintain their original soil structure (which I thought included their composition), then how are they expected to increase their void space? Aren't these two statements contradicting?

Reply: We are sorry for this misunderstanding.

(1) As literature illustrated, the decline of groundwater level has been observed in the study region during the drought periods (Leblanc et al., 2009), which would lead to the loss of the hydraulic connection between groundwater and surface water. The space that once was occupied by soil water becomes void. However, different backgrounds of soil types in the catchments may result in different change directions in the ACWSC. In sand and other soil types with a lower adhesive property, these soil pores would be compacted due to the reduction of buoyancy of soil water; thus the compacted soil may result in a decrease in the ACWSC. Conversely, these soil pores may be retained in those soils with a strong adhesive property; the decline of groundwater may lead to an increase in the ACWSC (Pan et al., 2020). The silt loam accounts for more than 45% of the total study area (Pan et al., 2020), Moreover, the silt loam possessed a strong field capacity and large adhesion property. The silt loam may maintain the original soil structure state even if the soil pore space increases due to the declined groundwater level, which may partly explain the increase in the ACWSC of the catchments.

(2) For clarification, the sentence in lines 543-546 would be modified as follows:
"In addition, the soil types in the study area include silt loam, loam, silt, sand, sandy loam, clay and loamy sand, among which silt loam accounts for more than 45% of the total study area (Pan et al., 2020). Moreover, the silt loam possessed a strong field capacity and large adhesion property. The silt loam may maintain the original soil structure state even if the soil pore space increases due to the declined groundwater level, which may partly explain the increase in the ACWSC of the catchments."
Please also refer to lines 638-644 in the revised manuscript.

B10. Line 564-565: '….other land-use types (grassland and farmland) was less, and the drought resistance ability of them was relatively stronger.' Are we talking about their ability to go dormant under water-limited conditions? If so, write explicitly.

Reply: Thanks for your comments.

(1) Sorry for the misunderstanding, but we are not talking about the dormancy capacity of vegetation here. Dormancy is the phenomenon of temporary suspension of growth and metabolism of a plant body or its organs at a certain period of

development. Forced dormancy is the phenomenon of temporary cessation of growth due to the stress of unfavorable external environmental conditions (low temperature, drought, etc.), and growth resumes when the adversity is removed. We are not sure which plant is more capable of forced dormancy.

(2) To live in an arid environment, plants must have the ability to resist drought: enhance water absorption, reduce water loss and store large amounts of water. What we want to say is that different vegetation may have different adaptive capacities under drought stress. Compared to evergreen broadleaf forests, vegetation of other land use types (grassland and farmland) may consume relatively less water, therefore we guess that these vegetation may be more likely to survive under relatively arid climatic conditions.

B11. Line 568-569: '…promoting the survival of the vegetation types with less water consumption but with higher water adoption ability.' Well, trees with low competitiveness with grass species will also survive. How is this connected to catchment characteristics, and where are these dynamics observed, since it has not been mentioned previously?

Reply: Thanks for your comments.

(1) The dynamics of vegetation cover are linked to the type of land use in the catchment. If the study area is covered by vegetation with low water consumption and high drought tolerance, then the persistent drought in the catchment may not be causing many trees to die, but may be causing an increase in water stress in the catchment.

(2) These dynamics are not our observations, but our speculations (or hypotheses) based on the historical literature and the results of this study. For example, the analysis of randomly distributed sites across the Australian savanna region by Fensham et al. (2009) showed that tree cover change was influenced by relative rainfall. This relationship is moderated by density dependence, whereby low woody cover promotes growth, and drought-induced dieback is more likely to occur at sites with relatively high densities of woody cover. The importance of rainfall patterns was also validated on a regional scale, as increases in woody vegetation during periods of above-average rainfall were offset by equivalent reductions due to drought. Excess and deficit rainfall is a strong determinant of woody vegetation dynamics in arid savannas (Fernandez et al., 2003). Allen et al. (2010) found that increases in the frequency, duration, and/or severity of drought and heat stress associated with climate change may fundamentally alter forest composition, structure, and biogeography in many areas. Therefore, we speculate that ecosystems within watersheds may already be shifting in response to climate change.

Added reference:

Fernandez-Illescas, C.P. & Rodriguez-Iturbe, I. Hydrologically driven hierarchical competition-colonization models: the impact of interannual climate fluctuations. Ecol. Monogr. 73, 207-222 (2003).

B12. The use of the 'significant' is still quite confusing. I think it's better to use relatively or considerably, etc.

Reply: Thanks a lot.

(1) As the minimum requirements for significant changes in storage capacity were set in this study: the change rate of the estimated parameter θ_1 (θ'_1) before and after the change point should exceed $|\pm 20\%|$. i.e., $\left|\frac{\theta_1^{'}-\theta_1}{\theta_1}\right| \times 100\% \geq 20\%$. Not all catchments with increased or decreased in ACWSC are analyzed in the results and discussion parts.

(2) In section 4.3 'Factors for shifts in the ACWSC', the word 'significant correlation' has been deleted in the revised manuscript to avoid misunderstanding.

B13. Still, I feel that the language and paragraph structure of the manuscript needs to be considerably improved.

Reply: Thanks for your comments. All the co-authors checked the written language carefully. We have once again invited a native English speaker to proofread the final manuscript.