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, 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. In the following Responses, comments by Editor are labeled E, comments by Reviewer #1 are labeled A, and comments by Reviewer #2 are labeled B. 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,

June 7th, 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

E1. as you have seen, the two reviewers highly appreciate the overall intention of your manuscript. They, however, also flag a number of critical issues that have to be clarified and resolved. I largely agree with this assessment. From my perspective, the most critical points that need to be addressed in detail are the following:

(1) Definition of catchment water storage capacity CWSC. Please provide a specific, clear and complete definition of what this system property is meant to be and what not. In other words, also clarify the differences to other properties (e.g., the root zone storage capacity).

In your replies, you have defined CWSC as "the water storage capacity [that] is defined as the maximum water volume that a catchment can hold after rainfall events. It referred to the part of effective rainfall that does not develop into the surface flow, and it was the sum of soil water storage capacity, vegetation intercept, and snowpack". While I agree that the root zone storage capacity does typically not account for interception evaporation, the effect of that remains rather limited as shown for example in Bouaziz et al. (2020, WRR). Some other parts of the definition are more critical.

Reply: Thank you for your professional comments. The CWSC defined by McNamara et al. (2011) is as follow: 'in an unregulated and unimpaired catchment, the water storage capacity refers to the maximum volume of water stored within a catchment and its distribution among groundwater, vegetation, surface water, soil moisture, and snowpack, which are the variables that ultimately characterize the state of the hydrological system'.

According to Perrin et al. (2003), parameter θ_1 in the GR4J model structure is the maximum capacity of the soil moisture accounting storage (i.e., the maximum capacity of the production storage), which consist of the groundwater storage, the canopy-interception storage, surface-interception storage, and soil-profile storage.

The parameter θ_1 was used to represent the primary storage of water in the catchment, which can reflect the main characteristics of the CWSC (Westra et al., 2014; Saft et al., 2015). The main difference between the definition of the parameter θ_1 and the CWSC is that the former does not account for snowpack storage (Perrin et al., 2003). In addition, in this study, 398 catchments in south-eastern Australia were selected for the case study. The annual mean precipitation and temperature range from 507 mm to 1814 mm and 8.26°C to 19.52°C, respectively. Thus, there is no obvious snowpack in these catchments (Saft et al., 2015; Pan et al., 2020).

For clarification, the definition of the CWSC has been updated in the revised manuscript (Lines 77-81) and as follows: The CWSC is defined as 'in an unregulated and unimpaired catchment, the water storage capacity refers to the maximum volume of water stored within a catchment and its distribution among groundwater, soil moisture, vegetation, surface water, and snowpack, which are the variables that ultimately characterize the state of the hydrological system' (McNamara et al., 2011).

References:
McNamara, J. P., Tetzlaff, D., Bishop, K., Soulsby, C., Seyfried, M., Peters, N. E., Aulenbach, B. T., and Hooper, R.: Storage as a metric of catchment comparison, Hydrol. Process., 25, 3364-3371, 10.1002/hyp.8113, 2011.

Perrin, C., Michel, C., and Andreassian, V.: Improvement of a parsimonious model for streamflow simulation, J. Hydrol., 279, 275-289, 10.1016/s0022-1694(03)00225-7, 2003.

Pan, Z. K., Liu, P., Xu, C. Y., Cheng, L., Tian, J., Cheng, S. J., and Xie, K.: The influence of a prolonged meteorological drought on catchment water storage capacity: a hydrological-model perspective, Hydrol. Earth Syst. Sc., 24, 4369-4387, 10.5194/hess-24-4369-2020, 2020.

Saft, M., Western, A. W., Zhang, L., Peel, M. C., and Potter, N. J.: The influence of multiyear drought on the annual rainfall-runoff relationship: An Australian perspective, Water Resour. Res., 51, 2444-2463, 10.1002/2014wr015348, 2015.

Westra, S., Thyer, M., Leonard, M., Kavetski, D., and Lambert, M.: A strategy for diagnosing and interpreting hydrological model nonstationarity, Water Resour. Res., 50, 5090-5113, 10.1002/2013wr014719, 2014.

E2. First it remains unclear how "rainfall"(!) can build up a "snowpack".

Reply: Sorry for our mistakes. The term 'rainfall' should be changed as "precipitation". In addition, the snowpack was not considered in these studied regions (Saft et al., 2015).

E3. Second, it remains unclear what is meant by "a catchment can hold". In the concept of root zone storage capacity this refers *uniquely* to the maximum water volume that *cannot* be released (directly or via the groundwater recharge) to the stream due to gravity. Instead, it can only be removed from the system via evaporative fluxes. In contrast, the inclusion of the snowpack in CWSC entails that part of the CWSC will in fact during snow melt be released to streams - not all of it will be evaporated/transpired. From that perspective, the term "storage" is very ambiguous as parts of that storage will sooner or later reach the stream.

Reply: Thank you for your comments. The term "hold" has been modified as "store" in the revised manuscript. The definition of the CWSC has been modified in the revised manuscript. Please refer to our reply to comment E1.

The parameter θ_1 of the GR4J model (Perrin et al., 2003) was used to represent the CWSC, and the snowpack was not considered in the GR4J model.

This estimate of storage does not account for the snowpack storage which is an unimportant storage mechanism in the studied catchments.

E4. Third, it is unclear how a snowpack can be constrained by an upper limit, because this is what the term "capacity" in CWSC entails. In contrast to water storage in the pores of the soil which obviously has an upper limit (i.e., field capacity), there is no direct physical limit to the snowpack, except for the amount of precipitation falling as snow.

Reply: Thanks for your comments. The snowpack was not considered in this study since it is an unimportant storage mechanism in these catchments.

E5. Fourth, it is completely unclear how the snow accumulation and melt were handled by the suggested version of GR4J. I am not sure that lumping it into the production store is a meaningful thing to do, as the production store does not depend on temperature and in most applications is meant to exclusively represent the soil water store.

Reply: Thanks. The adopted GR4J model did not have the snow accumulation and melt part (Perrin et al.,2003) and the snowpack was not considered in the study area (Saft et al., 2015). Please refer to our reply to comment E1.

E6. Fifth, while the term CWSC gives the impression of accounting for all of the storage in a catchment, storage in the groundwater is completely ignored. Why does the snowpack provide "storage" (although most of it will eventually be drained) and the groundwater not?

Reply: Thanks for your professional comments. Due to the limitation of the GR4J hydrological model, only a groundwater exchange term that acts on both flow components (i.e., quick and slow flows) was included in the GR4J model, and the groundwater storage was not considered in the model structure (Perrin et al., 2003).

E7. (2) the interpretation and discussion of the results needs to go into quite some more depth, including also a much more detailed description of the basis on which different conclusions are reached as well as a much stronger anchoring of the interpretation in the context of previous literature.

Reply: Thanks. Improved description of the results and discussion parts has been modified in the revised manuscript. Please refer to lines 519-592.

E8. (3) the language of the manuscript needs to be considerable improved. I strongly encourage to make use of the service of a native speaker.

Reply: We really appreciate your professional comments. All the co-authors checked the written language carefully. We have also invited a native English speaker to proofread the final manuscript.

E9. Please make sure to address the above points and all other comments provided by the reviewers in a detailed and meaningful way.

Reply: A point-to-point response has been made to address all comments raised by both reviewers. In the following Responses, comments by Reviewer #1 are labeled A, and comments by Reviewer #2 are labeled B.

I am looking forward to receiving a revised version of your manuscript,

best regards,

Reply to the reviewers' comments

Reviewer # 1

This study investigated the impacts of prolonged meteorological drought and asymptotic climate variation on catchment hydrology. The authors found that climate change has significant impacts on water storage capacity. Generally, I found this study is relatively novel, and fits well to the scope of HESS. And the results could benefit the community to further understand how terrestrial ecosystem responses to climate change, and their impacts on water resources. It has potential to be published in HESS. But I found some very important issues and biases, which need to be addressed before considering for acceptance.

Reply: We are grateful for the reviewer's appreciation of our work and for the professional comments, which are carefully followed in making revisions.

- A1. The catchment water storage capacity (CWSC) concept is not rigorous, and probably misleading. The CWSC is huge and unclear in most cases, which at least includes the water storage capacities of soil, groundwater, and surface water bodies, including rivers, lakes, and artificial reservoirs etc. In this study, the authors used the GR4J model, which has four parameters, θ1, θ2, θ3, θ4. The authors said "θ1 is the capacity of runoff producing reservoir in the catchment (mm)" and "θ3 is the capacity of catchment reservoir (mm)". I am confused with these statements, and the physical connection between CWSC and the θ1 and θ3 parameters. To my understanding, the authors may want to say the active catchment water storage capacity, i.e. the root zone storage capacity, which determines rainfall-runoff process, by splitting rainfall into infiltration and runoff. For more research and discussion on this issue, the authors can refer these papers: https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2014GL061668; https://hess.copernicus.org/articles/20/1459/2016/;https://hess.copernicus.org/articles/20/3361/2016/. In Line 509-513.

Reply: Thanks for your professional comments.

We are really sorry for our mistakes in the definition of model parameter θ_1 and θ_3. According to Perrin et al. (2003), Westra et al. (2014), and Pan et al. (2020), θ_1 refers to the production storage capacity in GR4J model structures, i.e., the catchment water storage capacity (mm). In addition, θ_3 denotes the one day ahead maximum capacity of the routing storage (mm) and is used to represent base flow (Harrigan et al., 2018). The definition of model parameter θ_1 and θ_3 have been updated in the revised manuscript.

The definition of the catchment water storage capacity (CWSC) was given by Mc Namara et al. (2011) and Pan et al. (2020) as follow: The catchment water storage capacity (CWSC) refers to the maximum volume of water stored within a catchment and its distribution among groundwater, soil moisture, vegetation, surface water, and snowpack, which are the variables that ultimately characterize the state of the hydrological system.

The “root zone storage capacity” refers to the maximum amount of soil moisture that can be accessed by vegetation for transpiration (Gao et al., 2014; Wang-Erlandsson et al., 2016; Sriwongsitanon et al., 2016; Singh et al., 2020). There is a strong association between the terms of the CWSC and “root zone storage capacity”, but they are different in definitions. For certain catchments, the value of the CWSC should be greater than or equal to root zone storage capacity. The values of the CWSC may be similar to the root zone storage capacity when the interception storage and snowpack capacity are zero.

No reference has been found with the illustration that parameter θ_1 in the GR4J model represents the root zone storage capacity. In addition, according to Perrin et al. (2003) and Nascimento et al. (1999), the interception storage capacity and the snowpack were not included in the GR4J model structure.

Meanwhile, according to Sriwongsitanon et al. (2016), four conceptual reservoirs have been included within the FLEX model structure, i.e., the interception reservoir (mm), the root zone reservoir representing the moisture storage in the root zone (mm), the fast response reservoir (mm), and the slow response reservoir (mm). It seems that the root zone storage capacity was a much more refined term when other parts of reservoirs have been defined. By contrast, the adopted GR4J model was a much more generalized and conceptual model to describe the rainfall-runoff process than the FLEX model.

Added references:

Harrigan, S., Prudhomme, C., Parry, S., Smith, K., and Tanguy, M.: Benchmarking ensemble streamflow prediction skill in the UK, Hydrol. Earth Syst. Sc., 22, 2023-2039, 10.5194/hess-22-2023-2018, 2018.

Singh, C., Wang-Erlandsson, L., Fetzer, I., Rockstrom, J., and van der Ent, R.: Rootzone storage capacity reveals drought coping strategies along rainforest-savanna transitions, Environ. Res. Lett., 15, 10.1088/1748-9326/abc377, 2020.

Sriwongsitanon, N., Gao, H. K., Savenije, H. H. G., Maekan, E., Saengsawang, S., and Thianpopirug, S.: Comparing the Normalized Difference Infrared Index (NDII) with root zone storage in a lumped conceptual model, Hydrol. Earth Syst. Sc., 20, 3361-3377, 10.5194/hess-20-3361-2016, 2016.

Nascimento, N. D. O., Yang, X., Makhlouf, Z., and Michel, C.:GR3J: a daily watershed model with three free parameters, Hydrol. Sci. J., 44, 263-277, 1999.

Gao, H., Hrachowitz, M., Schymanski, S. J., Fenicia, F., Sriwongsitanon, N., and Savenije, H. H. G.: Climate controls how ecosystems size the root zone storage capacity at catchment scale, Geophys. Res. Lett., 41, 7916-7923, 10.1002/2014gl061668, 2014.

Wang-Erlandsson, L., Bastiaanssen, W. G. M., Gao, H., Jagermeyr, J., Senay, G. B., van Dijk, A., Guerschman, J. P., Keys, P. W., Gordon, L. J., and Savenije, H. H. G.: Global root zone storage capacity from satellite-based evaporation, Hydrol. Earth Syst. Sc., 20, 1459-1481, 10.5194/hess-20-1459-2016, 2016.

- A2. the authors also mentioned that "the increased forest coverage of the catchment resulted in the larger water demand of the ecosystem, and thus a shorter response time of the CWSC to the meteorological drought." From this statement, I feel the authors also agree with me that the CWSC is a parameter related to ecosystem, rather than the total catchment water storage capacity. Also, they said "catchment has experienced a prolonged meteorological drought, it would respond fast due to its large water demand". Obviously, ecosystems have water demand, rather than soil or groundwater. Hence, both thought experiment and overwhelming evidences manifest that the root zone storage capacity of ecosystems determined the separation of rainfall to runoff and infiltration, rather than the total CWSC. Moreover, from the perspective of ecosystem response to climate change, the paper becomes more interesting, not only for hydrologists but also for ecologists etc.

Reply: Thanks. This is indeed a helpful comment. We agree with the comments that the CWSC is a parameter related to the ecosystem and refers to the active catchment water storage capacity that determines the rainfall-runoff process, rather than the total catchment water storage capacity. As our response to comment A1, clarifications about the meanings of the CWSC have been added in the revised manuscript.

The previous literature (Nicholls et al., 2004; Fensham et al., 2009; Allen et al., 2010; Adams et al., 2012) indicated that the variation in the forest coverage may be likely to induce the increase/decrease trend in the CWSC. Meanwhile, other literatures (Leblanc et al., 2009; Hughes et al., 2012; Saft et al., 2015) showed that different soil types and variation patterns (i.e., connected or disconnected) of the hydraulic interaction between the groundwater and the soil water may induce opposite variation trend in the active CWSC.

We have added Section 5.1 (Possible reasons for different changes in the CWSC) to discuss the possible connections between the soil types and forest coverage with the variation of the CWSC in the revised manuscript as follows (see Lines 520-570):

'The results showed that most catchments were identified to have an increasing trend in both the amplitude (α) and the mean value (δ) of the CWSC after prolonged meteorological drought. According to our findings, soil type and forest coverage are the variables the most related to the CWSC. The soil water holding capacities of various soil types were different due to the dissimilarity of void and adhesion in different soil types, which directly affects the ability of the catchment to absorb/store water, thereby affecting the CWSC of the catchment. Saft et al. (2015) showed that the annual rainfall-runoff relationships of many catchments changed in southeastern Australia during the millennium drought (1997-2009). The prolonged meteorological drought led to the continuous decrease of the groundwater level as well as a significant change in soil properties. Leblanc's study for southeastern Australia showed that only two years after the 2001 drought, soil moisture and surface water storage lost 80 and 12 km^3, respectively, and the rapid drying up reached near-steady low levels (Leblanc et al., 2009). Years of drought led to an almost complete drying up of surface water resources, and the hydrological drought continued even after rainfall resumed. 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 and loam account for more than 80% of the total study area (Pan et al., 2020). As both loam and silt loam have strong adhesion and water holding capacity, they can still maintain the original soil structure state even if the soil pore space increases due to long-term drought. Therefore, the combination of groundwater level decline and different pre-existing soil type conditions in each catchment may be one of the reasons for the different directions of change in the CWSC between catchments (Hughes et al., 2012). The decline in the groundwater level may lead to a gradual weakening of the hydraulic connection between surface water and groundwater, resulting in the potentially more voids in the soil and thus an increase in the CWSC in most catchments of the study area.

Furthermore, the variation of forest coverage and composition would affect the water holding capacity and water assumption ability, resulting in the potential changes in the CWSC. Previous studies (Fensham et al., 2009; Allen et al., 2010) showed that the increased frequency, duration of drought, and heat stress associated with climate change are strong factors contributing to changes in vegetation dynamics that may fundamentally alter forest composition and structure in many areas. Drought-induced vegetation dieback was more likely to occur in regions with relatively high densities of local woody cover. Adams et al. (2012) combined the extensive literature on the eco-hydrological effects of tree harvesting with existing studies to propose a new and relevant hypothesis. For most forests, evapotranspiration would be dramatically reduced after the significant dieback of the tree cover due to drought. According to Pan et al. (2020), the main land use types throughout the study area are evergreen broadleaf forest, grassland, woodland, and cropland. As the evergreen broadleaf forest and woodland occupied most of the study region, the notable loss of tree cover caused by the prolonged meteorological drought may dramatically reduce the evapotranspiration in catchments. Catchments with large coverage of evergreen broadleaf forest processed the large water demand per unit area (Adams et al., 2012). For comparison, the water consumption of catchments with other land use types (grassland and farmland) was less, and the drought resistance ability of them was relatively stronger. It can be hypothesized that in catchments with large coverage of vegetation, the occurrence of the prolonged drought may intensify the competition for water demand between different varieties of vegetation, promoting the survival of the vegetation types with less water consumption but with higher water adoption ability. Therefore, the catchments with high forest cover may lead to an increase in the CWSC.'

Added references:

Nicholls, N.: The changing nature of Australian droughts, Clim. Change, 63, 323-336, 10.1023/B:CLIM.0000018515.46344.6d, 2004.

Fensham, R. J., Fairfax, R. J., and Ward, D. P.: Drought-induced tree death in savanna, Global Change Biol., 15, 380-387, 10.1111/j.1365-2486.2008.01718.x, 2009.

Allen, C. D., Macalady, A. K., Chenchouni, H., Bachelet, D., McDowell, N., Vennetier, M., Kitzberger, T., Rigling, A., Breshears, D. D., Hogg, E. H., Gonzalez, P., Fensham, R., Zhang, Z., Castro, J., Demidova, N., Lim, J. H., Allard, G., Running, S. W., Semerci, A., and Cobb, N.: A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests, For. Ecol. Manage., 259, 660-684, 10.1016/j.foreco.2009.09.001, 2010.

Adams, H. D., Luce, C. H., Breshears, D. D., Allen, C. D., Weiler, M., Hale, V. C., Smith, A. M. S., and Huxman, T. E.: Ecohydrological consequences of drought- and infestation- triggered tree die-off: insights and hypotheses, Ecohydrology, 5, 145-159, 10.1002/eco.233, 2012.

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.

Hughes, J. D., Petrone, K. C., and Silberstein, R. P.: Drought, groundwater storage and stream flow decline in southwestern Australia, Geophys. Res. Lett., 39, 10.1029/2011gl050797, 2012.

- A3. The literature review is not comprehensive. There are already many important publications to understand both climate change and landuse change on time-variation of the root zone storage capacity. Please find more details here: https://hess.copernicus.org/articles/20/4775/2016/; https://hess.copernicus.org/preprints/hess-2021-204/.

Reply: Thanks for the comments and suggestions. The recommended publications and additional references (Gao et al., 2015; Nijzink et al., 2016; Singh et al., 2020; Laurène et al., 2021) have been added to illustrate the associations between the CWSC and the root zone reservoir capacity in the Introduction part of the revised manuscript.

Added references:

Gao, H., Hrachowitz, M., Schymanski, S. J., Fenicia, F., Sriwongsitanon, N., and Savenije, H. H. G.: Climate controls how ecosystems size the root zone storage capacity at catchment scale, Geophys. Res. Lett., 41, 7916-7923, 10.1002/2014gl061668, 2014.

Laurène, J. E., Bouaziz, Aalbers, E. E., Weerts, A.H., Hegnauer, M., and Hrachowitz, M.: The importance of ecosystem adaptation on hydrological model predictions in response to climate change, Hydrol. Earth Syst. Sc., 2021.

Nijzink, R., Hutton, C., Pechlivanidis, I., Capell, R., Arheimer, B., Freer, J., Han, D., Wagener, T., McGuire, K., Savenije, H., and Hrachowitz, M.: The evolution of root-zone moisture capacities after deforestation: a step towards hydrological predictions under change?, Hydrol. Earth Syst. Sc., 20, 4775-4799, 10.5194/hess-20-4775-2016, 2016.

Singh, C., Wang-Erlandsson, L., Fetzer, I., Rockstrom, J., and van der Ent, R.: Rootzone storage capacity reveals drought coping strategies along rainforest-savanna transitions, Environ. Res. Lett., 15, 10.1088/1748-9326/abc377, 2020.

- A4. The English writing is readable, but still has room to be improved. The improvement on writing might not take much time for the authors, but can significantly improve the presentation quality and increase its impact.

Hope these comments can be helpful to improve the quality of this manuscript.

Reply: We really appreciate your professional comments. All the co-authors checked the written language carefully. We have also invited a native English speaker to proofread the final manuscript.

Reviewer # 2

In this manuscript, the authors try to identify the temporal changes in the water storage capacity of the catchments in Australia due to prolonged meteorological droughts and highlight the factors responsible for causing such changes.

Based on my initial assessment of just the title, abstract and the research questions proposed in the Introduction, I found this research quite relevant for the larger hydrological and ecohydrological community exploring ecosystem response to droughts, changes to above- and below-ground water resources and predicting such changes under future climate change. However, after reading the manuscript, I had several major concerns.

Reply: We are grateful for your comments. A point-by-point response has been made to address all comments.

Major comments:

- B1. I was confused by the term 'catchment water storage capacity'. However, after reading the manuscript, I thought the concept explored in this study was similar to 'root zone storage capacity'. It would make sense to use terms already well established and accepted in the scientific community rather than introducing new terms. Authors should cite appropriate literature in the manuscript related to earlier and recent work about root zone storage capacity exploring their response under changing hydroclimate.

Reply: We sincerely appreciate your comments and our reply is as follows:

The term 'catchment water storage capacity (CWSC)' has been widely used in previous studies, such as Ali et al. (2010), McNamara et al. (2011), Westra et al. (2014), and Pan et al. (2019, 2020).

As our response to **comment A1** proposed by reviewer #1, the catchment water storage capacity (CWSC) refers to the maximum volume of water stored within a catchment and its distribution among groundwater, soil moisture, vegetation, surface water, and snowpack, which are the variables that ultimately characterize the state of the hydrological system (McNamara et al., 2011). In addition, according to Singh et al. (2020), the term "root zone storage capacity" refers to the maximum amount of soil moisture that can be accessed by vegetation for transpiration. There is a strong association between the terms of the CWSC and "root zone storage capacity", but they are different in definition.

Please also refers to our response to **comment A1** raised by reviewer #1. To improve the readability of our manuscript, more references (i.e., Singh et al., 2020; Gao et al., 2015; Nijzink et al., 2016; Laurène et al., 2021) have been added to describe the "root zone storage capacity" and its potential connections with the CWSC in the revised manuscript.

Added references:

Ali, A., Yazar, A., Aal, A. A., Oweis, T., and Hayek, P.: Micro-catchment water harvesting potential of an arid environment, Agr. Water Manage., 98(1): 96-104, 10.1016/j.agwat.2010.08.002, 2010.

Singh, C., Wang-Erlandsson, L., Fetzer, I., Rockstrom, J., and van der Ent, R.: Rootzone storage capacity reveals drought coping strategies along rainforest-savanna transitions, Environ. Res. Lett., 15, 10.1088/1748-9326/abc377, 2020.

Gao, H., Hrachowitz, M., Schymanski, S. J., Fenicia, F., Sriwongsitanon, N., and Savenije, H. H. G.: Climate controls how ecosystems size the root zone storage capacity at catchment scale, Geophys. Res. Lett., 41, 7916-7923, 10.1002/2014gl061668, 2014.

Laurène, J. E., Bouaziz, Aalbers, E. E., Weerts, A.H., Hegnauer, M., and Hrachowitz, M.: The importance of ecosystem adaptation on hydrological model predictions in response to climate change, Hydrol. Earth Syst. Sc., 2021.

Nijzink, R., Hutton, C., Pechlivanidis, I., Capell, R., Arheimer, B., Freer, J., Han, D., Wagener, T., McGuire, K., Savenije, H., and Hrachowitz, M.: The evolution of root-zone moisture capacities after deforestation: a step towards hydrological predictions under change?, Hydrol. Earth Syst. Sc., 20, 4775-4799, 10.5194/hess-20-4775-2016, 2016.

- B2. The authors have used the word 'asymptotic' (i.e., the influence of droughts/climate change on catchment's water storage capacity seasonally) quite frequently (every 3-4 lines in the Introduction) as a central research gap that is addressed in this manuscript. However, after reading the whole manuscript, I am still unsure how it was addressed. This is because authors haven't clarifyied how the trends observed in catchments due to prolonged meteorological droughts have permeated to show changes in seasonal hydrological trends of the catchments.

Reply: Thank you for your comments. The "asymptotic" characteristic refers to the periodic change pattern of the CWSC, which was denoted by the sine function of Equations (1) and (2) in section 3.2.2. More specifically, Equation (1) and (2) denotes the asymptotic/periodic change pattern of parameter θ_1 and θ_1' during the periods before and after the change-point, respectively.

As illustrated in lines 47-50 in the revised manuscript, the CWSC (which was represented by the parameter θ_1 of the GR4J model) may process the asymptotic (i.e., periodic change) pattern due to the seasonal growth and die-off of vegetation. In contrast, the occurrence of the prolonged meteorological droughts would result in another change pattern of the CWSC (i.e., named the extreme change pattern in this manuscript), which refers to the transformation of the variation patterns of θ_1 from Equation (1) to Equation (2).

In order to clarify this point, the following explanation of the "asymptotic change" of the CWSC have been added in section 3.2.2 of the revised manuscript (see lines 227-234):

'In this study, the potentially periodic variation characteristics of the CWSC (represented by model parameter θ1) was further included to reflect the asymptotic change within different periods (i.e., periods before and after the change-point), which was described by the sine function. The sine function is one of the most fundamental functional forms to represent the periodic change of variables (Westra et al., 2014; Pan et al., 2019a; Pan et al., 2019b). Furthermore, the potentially extreme change of the CWSC between the two periods was denoted by the variations between Equations (1) and (2).'

- B3. The authors had used the change in root zone storage capacity (i.e., catchment water storage capacity) before and after the prolonged droughts and correlated it with catchment and climate characteristics to infer relevant factors influencing the catchments. But does a high correlation mean causation as well? The authors have neither provided a concrete justification about probable catchment dynamics in response to the droughts nor cited a single literature in the 'Results and discussion', which makes it difficult to understand their reasoning. Furthermore, the characteristics of soil and forest cover are rarely discussed. Although these factors play a major role in influencing/partitioning storage and runoff of the catchments.

Reply: Thank you for your helpful comments. The correlation analysis method, as a statistical method, was used to explore the potential association between the variation in the CWSC and the variables of the catchment properties and climate characteristics. A high correlation did not imply 100% causation between them, but would provide us a potentially effective perspective for analyzing the logical relationship between them.

More discussions about the influence of different characteristics of soil and forest cover on the CWSC have been added in Section 5 'Discussion' part (5.1 Possible reasons for different changes in the CWSC) in the revised manuscript as follow:

'The results showed that most catchments were identified to have an increasing trend in both the amplitude (α) and the mean value (δ) of the CWSC after prolonged meteorological drought. According to our findings, soil type and forest coverage are the variables the most related to the CWSC. The soil water holding capacities of various soil types were different due to the dissimilarity of void and adhesion in different soil types, which directly affects the ability of the catchment to absorb/store water, thereby affecting the CWSC of the catchment. Saft et al. (2015) showed that the annual rainfall-runoff relationships of many catchments changed in southeastern Australia during the millennium drought (1997-2009). The prolonged meteorological drought led to the continuous decrease of the groundwater level as well as a significant change in soil properties. Leblanc's study for southeastern Australia showed that only two years after the 2001 drought, soil moisture and surface water storage lost 80 and 12 km^3, respectively, and the rapid drying up reached near-steady low levels (Leblanc et al., 2009). Years of drought led to an almost complete drying up of surface water resources, and the hydrological drought continued even after rainfall resumed. 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 and loam account for more than 80% of the total study area (Pan et al., 2020). As both loam and silt loam have strong adhesion and water holding capacity, they can still maintain the original soil structure state even if the soil pore space increases due to long-term drought. Therefore, the combination of groundwater level decline and different pre-existing soil type conditions in each catchment may be one of the reasons for the different directions of change in the CWSC between catchments (Hughes et al., 2012). The decline in the groundwater level may lead to a gradual weakening of the hydraulic connection between surface water and groundwater, resulting in the potentially more voids in the soil and thus an increase in the CWSC in most catchments of the study area.

Furthermore, the variation of forest coverage and composition would affect the water holding capacity and water assumption ability, resulting in the potential changes in the CWSC. Previous studies (Fensham et al., 2009; Allen et al., 2010) showed that the increased frequency, duration of drought, and heat stress associated with climate change are strong factors contributing to changes in vegetation dynamics that may fundamentally alter forest composition and structure in many areas. Drought-induced vegetation dieback was more likely to occur in regions with relatively high densities of local woody cover. Adams et al. (2012) combined the extensive literature on the ecohydrological effects of tree harvesting with existing studies to propose a new and relevant hypothesis. For most forests, evapotranspiration would be dramatically reduced after the significant dieback of the tree cover due to drought. According to Pan et al. (2020), the main land use types throughout the study area are evergreen broadleaf forest, grassland, woodland, and cropland. As the evergreen broadleaf forest and woodland occupied most of the study region, the notable loss of tree cover caused by the prolonged meteorological drought may dramatically reduce the evapotranspiration in catchments. Catchments with large coverage of evergreen broadleaf forest processed the large water demand per unit area (Adams et al., 2012). For comparison, the water consumption of catchments with other land use types (grassland and farmland) was less, and the drought resistance ability of them was relatively stronger. It can be hypothesized that in catchments with large coverage of vegetation, the occurrence of the prolonged drought may intensify the competition for water demand between different varieties of vegetation, promoting the survival of the vegetation types with less water consumption but with higher water adoption ability. Therefore, the catchments with high forest cover may lead to an increase in the CWSC.'

- B4. The manuscript's language needs to be improved considerably for it to be considered for acceptance in HESS. My main concerns are related to improper paragraph structure, grammatical inconsistencies (e.g., use of was, is and has been in the first paragraph of Introduction) and repetitions throughout the manuscript (e.g., Line 292-296 already mentioned in Methods). Although I have not included all inconsistencies that I found in the manuscript in this comment, the authors should check for them carefully.

  Reply: Thanks for your helpful comments. We have carefully checked the full text of the manuscript, modified the paragraph structure and grammatical inconsistencies, and deleted the repetitions in the revised manuscript. We have improved the written language through careful proofreading by all the co-authors, and also invited a native speaker to polish the final manuscript.

Specific comments:

- B5. The catchment's response to prolonged droughts would have already covered any seasonal response. Do authors think that using the word ''asymptotic' adds any value to the analysis presented?

  Reply: Thanks. Our previous study has identified the likely 'change point' of the CWSC after the occurrence of the prolonged meteorological drought (Pan et al., 2020). It assumed that the CWSC of the periods before and after the 'change point' was a constant value and an abrupt change may occur in the 'change point', but it did not consider the periodic change of the CWSC within the periods before and after the 'change point'. This manuscript is the prolongation of this previous study and further includes the periodic change of the CWSC during these two periods. The term 'asymptotic' used in this manuscript is to distinguish it from the 'abrupt changes' of the CWSC that was induced by the prolonged meteorological drought.

- B6. Line 55-62: Authors briefly discuss the strengths and weaknesses of statistical techniques but don't discuss the limitation of hydrological models. Is there none in the context of modeling, parameterization, etc.)?

  Reply: Thanks for your comments. More introduction about the limitations of the hydrological model have been added in the Discussion part of the revised manuscript as follow:

  'The GR4J model was used to address the response of the CWSC to the prolonged meteorological drought. The model processes a relatively simple structure with relatively low requirements for input data, and it has been widely used in rainfall-runoff simulation for small and medium-sized catchments (Dhemi et al., 2010; Demirel et al., 2013; Sezen et al., 2019; Kunnath et al., 2019). However, the GR4J model is implemented subject to restrictions and limitations due to the inadequate description of the runoff generation and flow confluence processes in the large catchments (e.g., larger than 10,000 km^2). Conceptual models usually consider the entire catchment to be one entity, then use empirical functional relationships or conceptual simulations to describe the runoff generation and flow confluence processes, and consequently adopt certain parameters with physical meanings to characterize the inhomogeneity of the spatial distribution of catchment characteristics. It has been argued that conceptual lumped rainfall-runoff models are far from being able to tackle the challenging problem of assessing the impacts of land-use or forest variation. The GR4J model lacks a physical foundation but seems to best detect changes in a basin behavior (Perrin et al., 2003).

According to Westra et al. (2014), θ_1 is the most sensitive parameter in the GR4J model and therefore was used to represent the CWSC in this study. The sine function was used to reflect the periodic change of the CWSC. Further studies are necessary to explore the impacts of different forms of functions on the identification and simulation of the periodic variation of the CWSC.'

Added references:

Demirel, M. C., Booij, M. J., and Hoekstra, A. Y.: Effect of different uncertainty sources on the skill of 10 day ensemble low flow forecasts for two hydrological models, Water Resour. Res., 49, 4035-4053, 10.1002/wrcr.20294, 2013.

Kunnath-Poovakka, A., and Eldho, T. I.: A comparative study of conceptual rainfall-runoff models GR4J, AWBM and Sacramento at catchments in the upper Godavari river basin, India, J. Earth Syst. Sci., 128, 10.1007/s12040-018-1055-8, 2019.

Sezen, C., and Partal, T.: The utilization of a GR4J model and wavelet-based artificial neural network for rainfall-runoff modelling, Water Supply, 19, 1295-1304, 10.2166/ws.2018.189, 2019.

- B7. Line 69-73: Is climate change not considered under changing environment? Are the authors claiming the hydrological models do not consider climate variability on catchments? Please provide appropriate citations to this statement.

Reply: Sorry for the misunderstanding. The changing environment included climate changes and human activity. For clarification, the phrase "the changing environment" was deleted in the revised manuscript and this sentence have been modified as follow:

"However, most of the previous studies on hydrologic response mainly focused on the variations in runoff response to climate change, without paying attention to the causality between the varying climates (i.e., extreme and asymptotic changes of climates) and variation in catchment properties."

Climate observations, e.g., rainfall and evaporation data, were necessary input for the hydrological model, thus the hydrological model already considered the climate change on catchment (Eregno et al., 2013; Karlsson et al.,2016; Kour et al.,2016).

References:

Eregno, F.E., Xu, C.Y., and Kitterod, N.O.: Modeling hydrological impacts of climate change in different climatic zones, Int. J. Clim. Chang. Str., 5(3):344-365, 10.1108/IJCCSM-04-2012-0024, 2013.

Karlsson, I. B., Sonnenborg, T. O., Refsgaard, J. C., Trolle, D., Borgesen, C.D., Olesen, J.E., Jeppesen, E., and Jensen, K.H.: Combined effects of climate models, hydrological model structures and land use scenarios on hydrological impacts of climate change, J. Hydrol., 301-317, 10.1016/j.jhydrol.2016.01.069, 2016.

Kour, R., Patel, N., and Krishna, A. P.: Climate and hydrological models to assess the impact of climate change on hydrological regime: a review, Arab. J. Geosci., 9(9):1-31, 10.1007/s12517-016-2561-0, 2016.

- B8. Authors have referred to a publication 'Pan et al. (2020)' as 'our previous study', and highlighted this study as the extension of the study mentioned above, addressing previous studies' time-based research gaps. I would recommend authors to dedicate one paragraph to 'Pan et al. (2020) to briefly discuss the necessary context, rather than discussing it in bits and pieces (Line 77-82, 103-105, etc.)

  Reply: Thanks. Changes have been made as suggested, and a brief description in one paragraph have been added in the revised manuscript to generalize the main findings of Pan et al. (2020) as follows:

  'Our previous study identified the impact of meteorological drought on the CWSC by investigating the changes in hydrological model parameters before and after drought events (Pan et al., 2020). Results showed that significant shifts in the CWSC were identified in almost two-thirds of the catchments in south-eastern Australia during the prolonged meteorological drought period. Two subsets of catchments with opposite response directions were identified in the study area, i.e., the subsets of catchments with the reduced and increased runoff generation rates, respectively. The main potential reasons may be the difference in the proportion of evergreen broadleaf forests in these catchments. We only considered the average shifts from the non-drought period to the drought period and treated the CWSC of each period as a constant while neglecting the time-varying characteristics of the CWSC of each catchment due to the periodic climate change, and thus was unable to reflect variation in catchment characteristics under asymptotic climate.'

- B9. Study area and Section 4.1 can be combined as 'Study area and catchment demographic' as it adds no novelty to the research gaps.

Reply: Thanks. Changes have been made as suggested.

- B10. Line 129-130: '….which had a significant impact on the stability of local ecosystems, and the development of society, economy and politics.' Add references which highlight this.

  Reply: Thanks for your comments. More references have been added and this sentence have been modified as follows:

  'which had a significant impact on the stability of local ecosystems and the development of society, economy, and politics (Nicholls et al.,2004; Hunt et al., 2009; Heberger et al., 2011; Potter et al., 2011; Hughes et al., 2012; van Dijk et al., 2013; Saft et al., 2015).'

  Added references:

  Heberger, M.: Australia's millennium drought: Impacts and responses, in The World's Water, (Chapter 5):97-125, Island Press, Washington, D. C, 2011.

  Hughes, J. D., Petrone, K. C., and Silberstein, R. P.: Drought, groundwater storage and stream flow decline in southwestern Australia, Geophys. Res. Lett., 39, 10.1029/2011gl050797, 2012.

  Hunt, B. G.: Multi-annual dry episodes in Australian climatic variability, Int. J. Climatol., 29, 1715-1730, 10.1002/joc.1820, 2009.

  Nicholls, N.: The changing nature of Australian droughts, Clim. Change, 63, 323-336, 10.1023/B:CLIM.0000018515.46344.6d, 2004.

  Potter, N. J., Petheram, C., and Zhang, L.: Sensitivity of streamflow to rainfall and temperature in south-eastern Australia during the Millennium drought, 19th International Congress on Modelling and Simulation (MODSIM), Perth, Australia, 2011, WOS:000314989303087, 3636-3642, 2011.

  Van Dijk, A. I. J. M., Beck, H. E., Crosbie, R. S., De Jeu, R. A. M., Liu, Y. Y., Podger, G. M., Timbal, B., and Viney, N. R.: The Millennium drought in southeast Australia (2001–2009): Natural and human causes and implications for water resources, ecosystems, economy, and society, Water Resour. Res., 49, 1040–1057, doi:10.1002/wrcr.20123, 2013.

- B11. Remove 116-119. Since the sections and subsections are already there, this paragraph is unnecessary.

  Reply: Thanks. Changes have been made as suggested.

- B12. Check the equation in section 3.3.2 Criteria (2).

Reply: Thanks. Done.

- B13. Line 253: NSE is abbreviated before it is defined. Authors can probably keep the un-abbreviated words for sub-headings.

  Reply: Thanks. Done.

- B14. Line 261: I still do not understand Criteria (3): Robustness requirements of the results. Clarify.

  Reply: Thanks for your comments. The illustrations about Criteria (3) have been added in the revised manuscript as below (see lines 278-282):

  'The initial values of model parameters were created three times to reduce their impacts on the final simulation results. Moreover, only the catchments that have significant changes in computation results will be taken as the final change items. If the simulation results meet such robustness requirements, the results would have the lowest dependency and the strongest stability on the adopted algorithm and model.'

- B15. Line 321: Avoid starting a sentence with a number.

  Reply: Thanks. Done.

- B16. Is the word 'significant' used to refer to statistical significance, i.e., $p < 0.05$? If so, make this clear in the manuscript and caption of the figures.

  Reply: Thanks.

  The term "significant" in this manuscript did not refer to statistical significance, but represented a significant difference in numerical changes in values. For instance, the criteria (2) (the minimum requirements for significant changes in storage capacity) in section 3.3.2, was used to evaluate whether the water storage capacity of the catchment has changed significantly/remarkably: the change rate of the estimated parameter θ_1 (θ'_1) before and after the change point should exceed 20%.

- B17. Line 334-337: Cite the appropriate table. The authors have also not adequately cited tables and figures in appropriate places. Check.

  Reply: Thanks a lot. Changes have been made as suggested, and the citation of relevant tables and figures have been added in the revised manuscript. Table 5 was related to lines 319-349 in the revised manuscript.

- B18. Line 407-408: '……while those of catchments with significantly downward changes in α are 391.9 and 422 days, respectively.' What does 'upward/downward change' mean? And why is the response time less than the upward change?

Reply: Thanks. Sorry for the misunderstanding. In this study, 'significant upward change' and 'significant downward change' mean 'significant increase' and 'significant decrease', respectively. For clarification, we have revised the relevant expressions in the manuscript.

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) are real or just sampling fluctuations.

- B19. 'Results and discussion' section needs to be structured properly. For example: Line 461-463: 'Since no strong correlation between the amplitude and a single factor is found, therefore we speculate that the potential change of the variation range of the CWSC is the result of the combination of various catchment features and climate factors.' Discuss what those feedbacks could have been. So far the 'Results and discussion' sections seem like just 'Results' without any citation justifying the claims made by the authors.

  Reply: Thanks for your comments. As our response to **comment B3**, the discussion part have been added in Section 5 in the revised manuscript and more references have been cited to verify our findings.

- B20. Line 439-445: 'On the whole, we can get the conclusion that: catchments with small area\ low elevation\ small slope range\ large forest coverage and AWHC soil may change more significantly than catchments with opposite characteristics. It is likely that the resilience of catchments with small area\ low elevation\ small slope range\ large forest coverage and high AWHC soil is poor, and which result in an easy change in CWSC of these catchments after the interference of meteorological drought.' Why would the resilience of a catchment with a low elevetion and high forest cover be poor? What is the reasoning here? Cite appropriately as well.

  Reply: Thanks a lot.

  Previous studies (Ferraz, et al., 2009; Fensham et al., 2009; Allen et al., 2010) have shown that persistent drought has led to massive vegetation mortality in southeastern Australia, and studies have hypothesized that tree mortality has led to the loss of canopy cover, directly altering evapotranspiration, transpiration, and canopy interception, and indirectly altering other hydrologic processes in the catchment, including infiltration, runoff groundwater recharge, and streamflow. Generally, for catchments with low elevation\high forest cover, their vegetation has high water consumption and is less resistant to drought compared to those in other catchments (Nicholls et al., 2004). 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 CWSC, and the dieback of trees in the forest may result in a significant change in CWSC (Adams et al., 2012). Thus, catchments with low elevation\high forest cover may be more susceptible to experience significant changes in CWSC compared to other catchments. In addition, as forests are formed through a long process of natural succession, they form a complete ecosystem and ecological balance relationship with understory vegetation and wildlife. When the ecological function of the forest is reduced due to the prolonged meteorological drought, it would take a longer time for the forest to grow and recover than other catchments. Therefore, the resilience of catchments with low elevation and high forest cover may be poorer compared to other catchments.

References:

Adams, H. D., Luce, C. H., Breshears, D. D., Allen, C. D., Weiler, M., Hale, V. C., Smith, A. M. S., and Huxman, T. E.: Ecohydrological consequences of drought- and infestation- triggered tree die-off: insights and hypotheses, Ecohydrology, 5, 145-159, https://doi.org/10.1002/eco.233, 2012.

Allen, C. D., Macalady, A. K., Chenchouni, H., Bachelet, D., McDowell, N., Vennetier, M., Kitzberger, T., Rigling, A., Breshears, D. D., Hogg, E. H., Gonzalez, P., Fensham, R., Zhang, Z., Castro, J., Demidova, N., Lim, J. H., Allard, G., Running, S. W., Semerci, A., and Cobb, N.: A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests, For. Ecol. Manage., 259, 660-684, 10.1016/j.foreco.2009.09.001, 2010.

Fensham, R. J., Fairfax, R. J., and Ward, D. P.: Drought-induced tree death in savanna, Glob. Change Biol., 15, 380–387, https://doi.org/10.1111/j.1365-2486.2008.01718.x, 2009.

Ferraz, S. F. D., Vettorazzi, C. A., and Theobald, D. M.:Using indicators of deforestation and land-use dynamics to support conservation strategies: A case study of central Rondonia, Brazil, For. Ecol. Manage., 257, 1586–1595, https://doi.org/10.1016/j.foreco.2009.01.013, 2009.

- B21. Line 487-493: ‘In general, soil and forest percentage are the most related variables to the mean value. The water holding capacity of various soil types is different as the dissimilarity of void and adhesion in different soil types, which directly affects the ability of the catchment to absorb and store water, and then affects the CWSC of the catchment. Furthermore, the coverage of multiple forest percentage would affect the water holding capacity and water assumption ability, resulting the potential changes in the CWSC.’ I would have preferred more soil and forest cover discussion on the catchment’s water storage capacity.

Reply: Thanks for your suggestions.

We have added Section 5.1 ‘Possible reasons for different changes in the CWSC’ to the Discussion part in the revised manuscript. Please refer to the **Reply of comment B3**.

- B22. I had concerns about some of the words that are used in the manuscript: ‘....different climate-changing patterns’ (Line 34), ‘stronger robustness’ (Line 170), ‘lumped conceptual’ (Line 178), ‘differentiated soil composition’ (Line 273), ‘remarkable increasing trend’ (Line 404), ‘remarkable convergence patterns’ (Line 355), and many more.

  Reply: Thanks for your detailed comments.

  ‘different climate-changing patterns’ (Line 34) have been modified as ‘climate change’.

  ‘stronger robustness’ (Line 170) have been modified as ‘more robustness’.

  ‘lumped conceptual’ (Line 178) have been modified as ‘a daily lumped rainfall-runoff model’.

  ‘differentiated soil composition’ (Line 273) have been modified as ‘differences in soil composition’.

  ‘remarkable increasing trend’ (Line 404) have been modified as ‘significant increased trend’.

  ‘remarkable convergence patterns’ (Line 355) have been modified as ‘obvious convergence’.

  Furthermore, many other sentences/phases have been corrected/modified in the revised manuscript.