Responses to all the Reviewers:

Dear Editor and Reviewers:

We sincerely appreciate the comments and advice from the Editor and Reviewers which have not only improved the quality of the current manuscript greatly, but also are beneficial for our research in general. We have carefully followed these comments in making revisions. Our detailed responses to the comments raised by the Editor and Reviewers are presented below. In the following Responses, for the sake of your evaluation, A1 represents comment 1 made by Reviewer #1, and B1 represents comment 1 made by Reviewer #2.

We look forward to hearing from you. Thank you for your time and efforts on our manuscript again.

Sincerely yours,

May 24th, 2022

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Reply to 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.

(1) 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 store capacity in its model structures, i.e., the catchment water storage capacity (mm). In addition, θ_3 denotes the one day ahead maximum capacity of the routing store (mm) and is used to represent base flow (Harrigan et al., 2018).

The definition of model parameter θ_1 and θ_3 will be updated in the revised manuscript.

(2) The definition of the catchment water storage capacity (CWSC) in this manuscript was adopted from Mc Namara et al. (2011) and Pan et al. (2020) and that was as follows: the water storage capacity 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. In addition, the "root zone storage capacity" referred 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).

Thus, there was a strong association between the terms of the CWSC and "root zone storage capacity", but there are different in definitions. For certain catchments, the value of the CWSC should be greater than or equal to root zone storage capacity. We guessed that the values of the CWSC may be similar to the root zone storage capacity when the interception storage capacity and snowpack were zero.

(3) 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 adopted 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.

For clarification, the definition of the CWSC and more references that included the recommended papers by reviewer #1 will be added in the modified manuscript.

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.

(1) We agree with the comments that the CWSC is a parameter that is 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 will be added in the revised manuscript.

(2) Most of 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, there was other literature (Leblanc et al., 2009; Hughes et al., 2012; Saft et al., 2015) showed that different soil types and different 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 will add 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:

'The results showed that most of the catchments are identified with an increasing trend in both the amplitude (α) and the mean value (δ) of CWSC. According to our findings, soil type and forest coverage are the most related variables to the CWSC. The soil water holding capacity is different as the dissimilarity of void and adhesion in different soil types, which directly affects the ability of the catchment to absorb/store water, and then affects 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), and 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 2 years after the 2001 drought, soil moisture and surface water storage lost 80 and 12 km^3 respectively, rapidly drying reached near-steady low levels (Leblanc et al., 2009). Years of drought led to almost complete drying of surface water resources and hydrological drought continued even after rainfall resumed. Therefore, the combination of groundwater level decline and the pre-existing different 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 appearance of 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) have shown 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 from the catchments would be dramatically reduced after the significant dieback of the tree cover due to drought. According to the literature (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 result in the dramatic reduction of the evapotranspiration in catchments. Catchments with large coverage of evergreen broadleaf forest that processed the large water demand (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 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 while with higher water adoption ability. Therefore, the catchments with high forest cover may lead to an increase of 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 comment and suggestions. The recommended publications and additional references (Gao et al., 2015; Nijzink et al., 2016; Singh et al., 2020; Laurène et al., 2021) will be 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:

(1) The term 'catchment water storage capacity (CWSC)' is not a new term but has been widely used in many historical studies within the field of hydrology, such as Ali et al. (2010), Westra et al. (2014), McNamara et al. (2011) and Pan et al. (2019, 2020).

(2) As our response to **comment A1** proposed by reviewer #1, the CWSC is the maximum water volume that a catchment can hold after rainfall events, and refers to the part of effective rainfall that does not develop into the surface flow, and it is the sum of soil water storage capacity, vegetation intercept, and snowpack. 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. Thus, there is a strong association between the terms of the CWSC and "root zone storage capacity", but there are different in definitions.

Please also refers to our response to **comment A1** raised by reviewer #1.

(3) 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) will be 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.

(1) 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 $\theta_1^{'}$ during the periods before and after the change-point, respectively.

(2) As illustrated in lines 214-215 in the manuscript, the CWSC (which was represented by the parameter θ_1 in 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).

(3) In order to clarify this point, the following explanation of the "asymptotic change" of the CWSC will be added in section3.2.2 of the modified manuscript:

'In this study, the potentially periodic variation characteristic of the CWSC (represent by model parameter θ_1) 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 functions. The sine function was 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 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.

(1) The correlation analysis method, as a statistical method, was used in this manuscript 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.

(2) More discussions about the influence of different characteristics of soil and forest cover on the CWSC will be added in Section 5 'Discussion' part (5.1 Possible reasons for different changes in the CWSC) of the revised manuscript, which was also presented as follows:

'The results showed that most of the catchments are identified with an increasing trend in both the amplitude (α) and the mean value (δ) of CWSC. According to our findings, soil type and forest coverage are the most related variables to the CWSC. The soil water holding capacity is different as the dissimilarity of void and adhesion in different soil types, which directly affects the ability of the catchment to absorb/store water, and then affects 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), and 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 2 years after the 2001 drought, soil moisture, and surface water storage lost 80 and 12 km^3 respectively, rapidly drying reached near-steady low levels (Leblanc et al., 2009). Years of drought led to almost complete drying of surface water resources and hydrological drought continued even after rainfall resumed. Therefore, the combination of groundwater level decline and the pre-existing different 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 appearance of 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) have shown 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 from the catchments would be dramatically reduced after the significant dieback of the tree cover due to drought. According to the literature (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 result in the dramatic reduction of the evapotranspiration in catchments. Catchments with large coverage of evergreen broadleaf forest that 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 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 while with higher water adoption ability. Therefore, the catchments with high forest cover may lead to an increase of 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 will be added in the Discussion part of the revised manuscript, which is also presented as follows:

'The GR4J hydrological model was used to address the response of the CWSC to the prolonged meteorological drought. The model processed a relatively simple structure and relatively low requirements for input data, and has been widely used in the 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 still subject to some restrictions and limitations due to the inadequate description of the runoff generation and flow confluence process in the large catchments (e.g., larger than 10,000 km^2). As the conceptual models usually recognize the entire catchment as a unit, and then use empirical functional relationships or conceptual simulations to describe the runoff generation and flow confluence processes, and 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 satisfactorily the formidable problem of assessing the impacts of land-use or forest variation. Ought the GR4J model lacks a physical foundation, but seems to be the best suited to detecting changes in a basin behavior (Perrin et al., 2003).

In addition, according to Westra et al. (2014), θ_1 was the most sensitive parameter in the GR4J model and was used for further parameterization in this study. One of the most basic forms, the sine function, was used to reflect the periodic change of the CWSC; further studies are still needed 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.

(1) The changing environment included climate changes and human activity. For clarification, the phrase "the changing environment" will be deleted in the revised manuscript and this sentence will be modified as follows:

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

(2) 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 will be added in the revised manuscript to generalize the main findings of Pan et al. (2020) as follows:

  ‘Our previous study has identified the impact of meteorological drought on CWSC by investigating the changes in hydrological model parameters before and after drought events (Pan et al., 2020). Results showed that a significant shift in the CWSC has been 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 have been 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 due to 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, and neglected the time-varying characteristics of the CWSC of each catchment due to the periodic climate change, and thus 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 will be 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 will be added and this sentence will be 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 will be 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) will be added in the revised manuscript as below:

  'Since the initial values of all unknown quantities may affect the final results of the model simulation, the initial conditions of the model parameters have been changed three times in this manuscript, only the catchments that were identified as significantly changed in each calculation would be identified as the final change items, which could ensure that the calculation results have the lowest dependence 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 will be made as suggested, and the citation of relevant tables and figures will be added in the revised manuscript. Table 5 was related to lines 334-337.

- 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 will revise 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 B2**, the discussion part will be added in Section 5 in the revised manuscript and more references will be 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 will add 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) will be modified as 'climate change'.

  'stronger robustness' (Line 170) will be modified as 'more robustness'.

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

‘differentiated soil composition’ (Line 273) will be modified as ‘differences in soil composition’.

‘remarkable increasing trend’ (Line 404) will be modified as ‘significant increased trend’.

‘remarkable convergence patterns’ (Line 355) will be modified as ‘obvious convergence’.

Furthermore, many other sentences/phases will be corrected/modified in the revised manuscript.