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Reply on RC2

Yunfan Zhang et al.

Author comment on "Drought-induced non-stationarity in the rainfall-runoff relationship invalidates the role of control catchment at the Red Hill paired-catchment experimental site" by Yunfan Zhang et al., Hydrol. Earth Syst. Sci. Discuss.,
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Response to Reviewer #2

This manuscript investigates the discrepancy of estimated vegetation influence on catchment run-off based on three established methods for one paired catchments site in Australia. The particular pair had been the only one showing strong discrepancies in an earlier study (Zhao et al., 2010, cited in the manuscript). The three methods are: (a) „paired-catchment method“ comparing control and treatment catchment runoff (b) „time-trend analysis method“, comparing rainfall-runoff dynamics before and after the treatment only in the treated catchment (c) „sensitivity-based method“, comparing observed and modelled „climate affected only“ runoff in the treated catchment. The modelled runoff is derived from un-calibrated prediction of precipitation partitioning into runoff and evapotranspiration based on the aridity index and is supposed to mimic the variation in catchment runoff related to climate variation alone. Only method (a) uses both catchments, while (b) and (c) only rely on the treated catchment (although awkwardly almost no data are presented on that one, see below). The main attention of the manuscript lies in investigation of the suitability of the paired catchment approach. The authors re-visit the catchments using a longer time series and also applying a lumped hydrological model. They identify changes in the overall rainfall-runoff-relation that coincide with a prolonged drought period in Australia, and conclude that the main assumption of the paired catchment approach (e.g. „stationarity“) is violated. When using modelled runoff for the control catchment based on the pre-drought parameters (e.g. imposing stationarity) instead of the real measurements, the results match better with two other alternative approaches. The authors conclude that non-stationarity was the main reason for the discrepancy between the three methods used to evaluate the effect of land cover change on catchment runoff.

The question how land-use change affects catchment run-off is certainly an important one given the ongoing anthropogenic changes of landscapes. Contributions to improving methods for detecting those effects are of interest for the readership of HESS. Overall the paper is well written and mostly well-organized. I have some serious concerns about the conclusions drawn from the analysis as I think they are flawed. Unfortunately, I also have major concerns about the motivation and presented material. My concerns are severe and would require a substantial revision of the basic approach, such that I recommend

rejection at this point. I believe investigation could gain in merit, if argumentation and analysis were rendered consistent between the two catchments, methods were compared in a balanced fashion and more focus was placed on underlying processes.

Reply: Thanks very much for your great efforts to assess our manuscript. We have studied your and reviewers' comments carefully and made corrections/revisions as suggested. In the following, we have detailed how these comments are raised and our responses and revision.

Serious Concerns:

- I find that the study's main conclusion is based on a flawed assumption that the rainfall-runoff dynamics in the control catchment was affected by the drought, while the one in the treatment catchment was not. This assumption is arbitrary, not stated and its implications not discussed. All potential causes mentioned in the discussion for the changing rainfall-runoff relation in the control catchment (change of catchment capacity due to lower groundwater levels, increases in potential evaporation), would equally apply to the directly neighboring treatment catchment. The assumption that this is not the case is without basis. Indeed, the results of the three applied methods matching after the „correction“ may be by accident.

Reply: Thanks for these constructive comments.

We agree that the study's main conclusion is based on a flawed assumption that the rainfall-runoff dynamics in the control catchment was affected by the drought, while it was not considered in the treatment catchment. Regarding to the hypothesis, whether prolonged drought has altered the rainfall-runoff relationship in the treated catchment is not tested or made explicitly in the manuscript mainly due to two reasons. One is whether prolonged drought will lead to changes in the rainfall-runoff relationship is still controversial. Saft et al. (2015) examined whether interdecadal drought induces changes in the rainfall-runoff relationships in 158 catchments in south-eastern Australia according to annual rainfall and runoff records. It is found that protracted drought led to a significant shift in the rainfall-runoff relationship in 46% of the catchment-dry periods studied and a globally significant change in the rainfall-runoff relationship in 34% of the catchment-dry periods. But, the rainfall-runoff relationship of a small part of catchments did not change significantly, even if they suffered from long-term drought. The other reason is that it will be difficult to validate that prolonged drought has altered rainfall-runoff relationship of the treated catchment as there will be two drivers (i.e. prolonged drought and afforestation) and contributions cannot be separated or identified independently based on single catchment observations. Nonstationary assumption was only made and tested in the control catchment and we believe this is the only assumption can be tested and validated faithfully based on current understanding and observations. Therefore, we only stated that estimated changes in rainfall runoff relationship using three methods will be consistent if shift in rainfall-runoff relationship of the control catchment is restored (i.e. imposing stationarity as you stated). Whether prolonged drought has induced rainfall-runoff relationship change in the treated catchment and how to separated were not conducted in the manuscript.

We agree that all potential causes mentioned in the discussion for the changing rainfall-runoff relation in the control catchment would equally apply to the neighbouring treatment catchment. Therefore, prolonged drought may also change the rainfall-runoff relationship of the treated catchment. According to reviewer's comments, rainfall-runoff relationship of the paired catchments and whether further assumption on the rainfall-runoff relationship change induced by prolonged drought can be made were re-examined and investigated carefully. Actually, by imposing stationarity to the control catchment, the consistent results using three methods in the manuscript represent the contribution percentage of

both prolonged drought and vegetation change to the runoff reduction. We would like to make this further assumption as suggested and the new framework and methodology is stated in a separated document as attached. Methodology and results of the manuscript will be revised accordingly.

- The study states that „stationarity“ is a main assumption for method (a). Indeed, the basic assumption is that catchments would respond very similarly, if they had the same vegetation. Strictly speaking, this does not imply that their rainfall-runoff behaviors cannot change over time.

Reply: Thanks for these constructive comments. We agree with your opinions.

When the treated catchment is not reforested, the response of hydrological process to prolonged drought in the treatment watershed should be similar to that in the control watershed. On this basis, the runoff-runoff relationship of the two catchments should be relatively stationary before and after the prolonged drought. Therefore, the assumption of the paired catchment method is relatively stable and robust.

- Following up on 1 the study only investigates the violation of assumptions in one of the three methods, while the others are taken as approximately correct. Alternative hypotheses are not discussed. Method (a) has great potential to covering the effect of climate variation properly. Its main assumption is that the catchments would respond similarly, if they had the same vegetation. Any differences in catchment behavior (e.g. catchment storage capacity) that are the result of the treatment are arguably still a vegetation effect. However, it would be interesting to investigate whether the catchments generally behaved differently at drier conditions which were not observed during the „pre-treatment“ period. Method (b) assumes that the parameters of the treated catchment do not change over time. This assumption was clearly violated in the control catchment as the authors show at length, while the treated catchment was not investigated for it. From their own investigation, the authors should be highly skeptical that the assumption can be made. Method (c) ignores catchment processes, and assumes that rainfall partitioning only depends on aridity. This approach assumes that changes in catchment storage can be ignored (stationarity), which contradicts the conclusions made for the control catchment, e.g. changed catchment capacity due to lower groundwater tables during the drought. In other words, to me method (a) appears the most robust compared to the other two, given the presented results. The comparison of the methods requires more balanced assessment and more scrutiny. Currently the manuscript is inconsistent.

Reply: Thanks for these constructive comments. We fully agree with reviewer’s comments and suggestions.

- Considering the influence of prolonged drought on the rainfall-runoff relationship in the treated catchment, the result of the paired catchment method is closest to the real runoff change caused by vegetation change. Because the control catchment indirect eliminate the influence of prolonged drought and climate variability on the treated catchment under the assumption that the response of the two catchments to prolonged drought is similar.
- The time-trend analysis method only can eliminate the influence of climate variability (it does not change the rainfall-runoff relationship) on runoff in the treated catchment. This method assumes that only vegetation change causes the change of rainfall-runoff relationship. But in the manuscript, runoff changes calculated by the time-trend analysis method are actually induced by vegetation change and prolonged drought.
- Interannual changes in watershed storage occur primarily in soil water and shallow groundwater, pools that are often hydrologically active at time scales shorter than 1 year (Sayama et al., 2011). Rice and Emanuel (2019) indicates that down□regulation

of transpiration and inhibition of hydrologic connectivity by forest vegetation represent two important negative feedback processes that can avert large losses in soil water or plant-accessible groundwater during dry periods. In doing so, this feedback mechanism has the potential to reinforce steady-state (or near-steady-state) conditions in dry conditions. So, the sensitivity-based method may be less affected by the prolonged drought because it is used in the forest and the time scale of PET and P data used in this method is annual scale. Runoff changes calculated by the sensitivity-based method are induced by climate variability.

In the revised manuscript, framework and methodology will be revised significantly according to comments and suggestions. More details about the new methodology and new results are stated in a separated document as attached.

Major concerns:

- The motivation is very vague and so is the conclusion. It states very generally that the community can learn from assessing the discrepancies in this one catchment pair, but the derived conclusions are not novel. Already the study of Zhao et al., (2010, cited in the manuscript) came to the same conclusion. So it is unclear how this analysis adds more knowledge.

Reply: Thanks for these constructive comments.

The purpose of the manuscript is to find the reason for the big difference amongst results calculated by the paired catchment method, the time-trend analysis method and the sensitivity-based method, and estimate the actual influence of prolonged drought, vegetation change and climate variability on runoff of the treated catchment. They have not been done before and are the major advances of this study.

In the separated document as attached, we revised the main assumptions, calculation process and results, and we analysed the results using three different methods. Based on the modified results, we have the following new findings:

- In the case of prolonged drought, the time-trend analysis method and the sensitivity-based method will significantly overestimate the impact of vegetation change on runoff.
- We proposed a new method to separate the effects of vegetation change and prolonged drought on rainfall-runoff relationship of the treated catchment. This new method applies time-trend analysis method to observed runoff of the control catchment (combination of the paired catchment method and time-trend analysis method).
- We use statistical methods and physical model to verify that prolonged drought can induce non-stationarity in the control catchment. And we further proved and estimated the influence of prolonged drought on the rainfall-runoff relationship of the treated catchment based on the new method and observations of the control catchment.
- The entire investigation is awkwardly focused only on the control catchment. For example, of the eight figures dealing with catchment runoff only one also shows the treated catchment, the others only the control catchment. As such, the study boils down to investigating the effect of the drought on catchment runoff - but if this was the focus of the study, the methods much more than now should try to look into the catchment processes.

Reply: Thanks for these constructive comments. We admit there are some flaws in the original manuscript. Verifying that prolonged drought changed the rainfall-runoff relationship of the control catchment is the first step of this study. Stationary test of the control catchment is to better verify and estimate the response of the rainfall-runoff

relationship to prolonged drought in the treated catchment. The non-stationary rainfall-runoff relationship of the treated catchment induced by prolonged drought should be re-examined and investigated.

In the revised manuscript, assumptions and methodology will be revised significantly according to comments and suggestions. More details about the new methodology and new results are stated in a separated document as attached.

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Please also note the supplement to this comment:

<https://hess.copernicus.org/preprints/hess-2021-5/hess-2021-5-AC2-supplement.pdf>