Rebuttal

Dear editor,

Thank you for your decision on the manuscript and providing the opportunity to further deepen the discussion on modeling results. Following your directions, we have indeed decided to add a critical reflection in section 5.1. We also added more nuances in sections 5.2, 5.3 and the conclusions, as requested.

We believe these additional revisions have further clarified the concerns of the reviewer and contribute to a nuanced interpretation of our results.

Best regards, on behalf of all authors,

Ileen Streefkerk

Section 5.1

We have added the following paragraphs to section 5.1 which include a more critical reflection on assumptions of the framework.

"We also reflect on the modelling framework by comparing the calibration results and the uncertainty ranges of model results. Here we distinguish 1) (calibrated) *parameter sets* which mostly control (socio-)hydrological properties (Figure 4), and 2) different *initialisation settings* for the agents household characteristics (Figure 5), which may indirectly impact the hydrological simulations.

These results show that the severity of the simulated drought hazards are very unsensitive to our *initialisation settings*. Note that we do see a spatial-temporal pattern in the severity of drought event, but this pattern is not dependent on the *parameters settings*. However, with regard to drought impact, we do find that both the *parameter sets* and *initialization settings* substantially affect the results in different ways. For example, crop production is sensitive to different parameters sets but not to the initialisation settings. This indicates that 'crop production' is not much influenced by household characteristics, but is mostly affected by water availability. This finding is also observed in the sensitivity analysis by Streefkerk et al (2023) using the same model setup where the 'irrigation factor' was found to be the most influential parameter for crop production outcomes. This may explain why in this paper limited differences among the scenarios are observed in terms of crop production, as the 'irrigation factor' nor rainfall was changed between the scenarios. Only 11 % of the agent population have both access to irrigation and are located near a river. This can be an explaining factor of why the changes in streamflow and groundwater due to commercial farming activities have minimal effect on the drought impact variable crop production. The other drought impact variable distance to household water is, however, more sensitive to household characteristics than water availability, while the drought impact variable milk production is sensitive to both household characteristics and water availability. For example, the household characteristic 'network radius' determines the extent of the area where agents can look for water and grass and thus influence the distance to water and milk production. This also relates to assumptions within the model decisions rules, for example the prioritisation of water allocation, whereby domestic water demand is prioritised over livestock and crop demand. This assumption is reflected in the results, as most of the effect on drought impacts among the different scenarios is observed in the distance to household water.

Notably, soil moisture appears to be only weakly connected to groundwater levels (Quichimbo et al., 2021). Only a small upward trend in difference of soil moisture levels over the simulation period is observed, despite the strong upward trend of difference of groundwater levels in the *communities* and *forest* scenarios (Figure 6), caused by the strong downward trend in groundwater levels in the commercial farms scenario. Furthermore, the additional runoff generated by return flows from groundwater abstraction related to the commercial farming activities may partially offset the effects of river abstraction and groundwater levels on river discharge (De Graaf et al., 2014). Finally, the limited effect of commercial farms activities may also be influenced by the spatial scale of the analysis, as the scenario area is relatively small compared to the studied area (200 km^2, vs 5500 km^2). Other studies in the catchment area have found significant local effects on river discharge (Ngigi et al., 2008; Lanari et al., 2018; see Section 5.2), showing that strong local effects can average out on the larger catchment scale.

There are also model assumptions regarding the commercial farming activities (see also Section 5.2). One of which is that the groundwater extraction of the farms is limited by abstraction rate defined by their permits, and not by abstraction depth (i.e., physical limits on well depth) or increasing abstraction costs for example related to electricity or fuel costs. This could lead to both an overestimation or underestimation of groundwater abstraction compared to real values. Abstraction could be overestimated as farms may not reach the maximum groundwater well depths in times of lower groundwater tables, limiting their abstraction. On the other hand, abstraction could also be underestimated, as abstraction rates reported by permits may not necessarily reflect actual maximum abstraction rates (Aeschbacher et al., 2005), with farmers possibly abstracting more than their permits. Also, the reservoirs of the commercial farms are perhaps modelled more efficiently than in reality: in our model, open water evaporation of the reservoirs is not included. Together these two assumptions related to groundwater and surface water may result in an underestimation of river abstraction and over- or underestimation of groundwater abstraction in the commercial farm scenario.

Essentially, our model setup with a coupled agent-based and hydrological model allows to assess the impacts of humans on water, and of water on humans. Based on our results, we can conclude that the impact of commercial farming activity on water resources is quite limited within this basin, while the impact of water on human behaviour is significant (see Section 5.2). This is likely due to the relatively small area of commercial farms as compared to the entire basin. Therefore, one could argue that other modelling frameworks that do not include feedbacks between human behavior and the water system could have led to similar outcomes. Examples of such other hydrological models that include human activities (e.g. Wada et al, 2014), surface and groundwater interactions (De Graaf et al., 2014) and can compute drought impacts (De Wit, 2013). However, we did not know this beforehand, so we could not have the impacts of human behavior on the water system. Using the agent-based model to simulate the influence of water resources on human behavior has allowed us to investigate some impacts and feedbacks that are unique to agent-based modelling (see Section 5.2). Furthermore, we argue that such a coupled model setup is fit-for-purpose and is more widely applicable and can be used in other contexts where the influence of human behaviour is more significant (e.g., the Bhima basin; Kalthof et al., 2025), and is thus more widely applicable than a model that only uses one-way and fixed impacts.

Sections 5.2

Although minimal differences in drought impacts among the different scenarios are observed for the average population, large variations in drought impacts are observed within the agent population (5th and 95th percentile), when comparing the *forest* and *communities* to the commercial farms scenario. These findings suggest that the impacts of the commercial farming activities are spatially variable. The largest differences are observed with respect to the *communities* scenario, which can be explained by the additional agents that are present in the model in that scenario. This suggests that drought impacts are impacted by other agent's activities and that a cascading socio-hydrological interactions largely influence outcomes in drought impacts.

5.3 and conclusion

Please see the track-changes of these sections in the manuscript, where we improved acknowledgment and explanation of the minimal differences among the scenarios.

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