Response to comments made by a member of the scientific community 2 on a manuscript entitled 'Changes in mean evapotranspiration dominate groundwater recharge in semi-arid regions'

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Community comment 2

General comment 1: The present paper addresses the impact of changes in rainfall distribution and potential evapotranspiration on groundwater recharge (GR) in semi-arid areas. In their introduction based on the scientific literature, the authors note that "no conclusive generic outcomes can be drawn regarding the relationship between changes in climate conditions and the resulting changes in GR rates", "it is unclear whether the climate variability is amplified or smoothed in the GR response" and "even the trend of the GR response is uncertain". These assessments are reasonable and I fully agree with them.

Reply to general comment 1: *These assessments were drawn from previous studies, and those are cited in the paper.*

General comment 2: Several factors may explain this large range of GR responses to present climatic changes, which leads to apparent contradictions in their recent evolution. The first explanation is the variability of environmental conditions in the natural state. The second explanation is the multiplicity of scientific approaches (various methods using various types of data sets monitored at different scales in space and over time), which logically lead to heterogenous results. Moreover, depending on methods, the calculated GR represents an integration over a very variable time. The third explanation is that in the last decades GR may have changed a lot as a consequence of the climate change and the multifaceted human modifications of semi-arid landscapes (e.g. changes in land use and land cover; water conservation works). The GR estimates found in the literature aggregate values from various stages of this evolution between areas still in a mostly natural state and others deeply modified. Depending on areas, direct human intervention may be a much stronger factor than climate change. For instance, the increase in GR by one order of magnitude in southwestern Niger (e.g. Favreau et al., 2009) and by two orders of magnitude in eastern Australia (e.g. Allison et al., 1990) was explained by a change in the vegetation cover only. Therefore raw data from

the literature should be used with a cautious reference to their specific contexts, which is not really the case in the submitted text.

Reply to general comment 2: *We agree with the reviewer's perspective regarding the large uncertainty in the reported groundwater recharge fluxes (see reply to general comment 2 of reviewer #1). We believe that the explanations provided by the reviewer can clarify why our model did not adequately fit some of the reported groundwater recharge fluxes. This description has been added to the revised text, along with relevant references.*

We revised the text to include the explanations above (lines 67-72).

General comment 3: An important concern is the geographical extent of this work. The authors used GR estimates from 200 semi-arid locations in different continents, in a wide range of soils and climate conditions. The annual rainfall in the sites considered ranges from 180 to 1044 mm, with more than one half between 400 and 600 mm. In fact, 60 % of the sites are in Australia, 20 % in Africa, 10 % in North America and 10 % in the other continents, which differs significantly from the distribution of semi-arid areas in the world. Does this selection bias the final conclusions? The Figure 1-a will probably surprise many readers who usually see a much larger extent of semi-arid areas in global maps; this singularly restricted coverage should be justified.

Reply to general comment 3: *We compare the cumulative distribution of results from 67 randomly sampled locations in Australia with the 67 locations outside Australia in the graph below. The comparison clearly shows that changes to the mean E_p would considerably change the R/P ratio in Australia and other arid and semi-arid locations. This result supports our interpretation that the results are not limited to the region of Australia.*

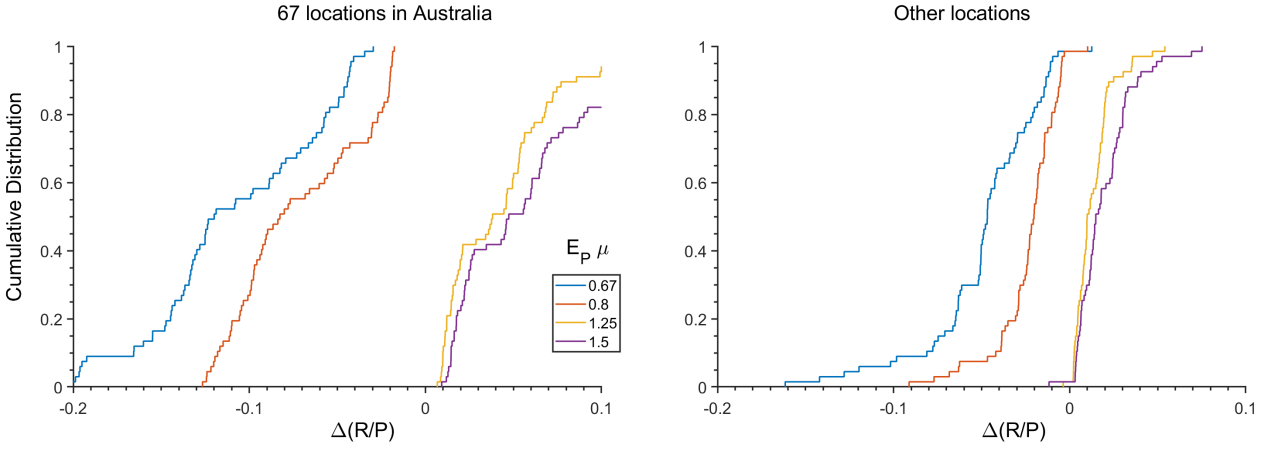

Figure 1. Cumulative distributions of the change in the R/P ratio, $\Delta(R/P)$, for 67 random locations in Australia (left panel) and 67 locations in other continents (right panel). The different lines indicate different changes in the mean E_p.

General comment 4: Another important concern is the very restrictive assumptions for the calculation: (i) GR occurs only through diffuse recharge (i.e. without any focused recharge); (ii) transpiration is negligible vs. evaporation; (iii) surface runoff is negligible; (iv) there is no preferential flow in the unsaturated zone. The fist assumption contradicts the observation that focused and diffuse recharge often coexist in the same area. Their respective proportions depend on local geomorphological conditions (e.g. Cuthbert at al., 2019). At the global scale, it is generally accepted that the proportion of focused recharge increases with aridity and as a consequence the driest semi-arid regions would be excluded from this calculation. The second assumption neglects transpiration uptake while the vegetation cycle in semi-arid areas is closely linked with the rain distribution, which is also the driver for GR. The third assumption requires to limit the application of the calculation to very flat areas and/or very low rainfall. The fourth assumption requires a very poor biological activity (roots and fauna).

These four assumptions together are so constraining that the geographical extent of the concerned semi-arid areas is probably very small. The practical relevance of this text appears therefore limited and the added value for researchers working on groundwater in semi-arid areas may be seriously questioned. The authors are conscious of these weaknesses and in their conclusion they mention the possibility of extending their work, but this last precaution is not enough to give the text a convincing strength.

Reply to general comment 4: *We conducted our analysis using locations where ground-based methods are employed to estimate groundwater recharge. Methods like chloride mass balance (CMB) and water isotopes are typically used to assess diffuse recharge. While these methods can indicate focused recharge, they may not efficiently quantify the focused recharge component. Additionally, we did not ignore transpiration; rather, we excluded locations with significant plant cover to reduce uncertainty and focus on illustrating the effects of changes in precipitation and potential evapotranspiration on groundwater recharge. Previous paper presented contradicting results regarding the effect of future projections on groundwater recharge. n our study, we propose potential sources of uncertainty and recommend that future studies analyze climate statistics initially to better explain projected changes.*