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review for egusphere-2022-22 by Seraphin et al.

Anonymous Referee #2

Referee comment on "Influence of intensive agriculture and geological heterogeneity on the recharge of an arid aquifer system (Saq–Ram, Arabian Peninsula) inferred from GRACE data" by Pierre Seraphin et al., EGUsphere, https://doi.org/10.5194/egusphere-2022-22-RC2, 2022

This is a review for the article: "Influence of intensive agriculture and geological heterogeneity on the recharge of an arid aquifer system (Saq-Ram, Arabian Peninsula)" by Seraphin and colleagues. Seraphin and colleagues present a method that combines GRACE satellite products with Global land data assimilation model outputs into a simple regional water balance model for the estimation of regional groundwater recharge rates. Furthermore, the importance of artificial recharge from irrigation return flows is evaluated and compared to the estimated natural groundwater recharge rate, as is the importance of recharge over the comparably limited geographic extents of volcanic deposits (with both artificial recharge and recharge over volcanic deposits being hugely important for the aquifer system). The study is very well researched, presented and written, and can provide guidance to similar estimations for other data scare regions. I have only few minor concerns that I list below. Once these points have been addressed, I recommend moving forward and accepting the article for full publication in HESS.

Minor Comments:

General:

- The abstract is generally well written, clearly describes the goals, the data sources as well as the results. However, no details on the applied method are provided. I suggest reducing mentioning the different datasets and GRACE solutions in such detail, as writing out the different names plus providing the abbreviations consumes way too much space. The freed up space I suggest using for a sentence on the applied methodology, for

example, linking to the first sentence of section 2.4: "The data was used to build a regional-scale water mass-balance and estimate recharge from variations in groundwater storage"

- I appreciate that uncertainties are provided for every number, a sign of a thorough analysis and something that is too often absent missing in similar analyses. Nevertheless, the uncertainties seem very small for satellite based assessments of recharge over such a large domain. Based on the numbers provided (i.e., 4.4 +/- 2.6%), Seraphin et al suggested that recharge rate of the entire Saq-Ram Aquifer lies between ~2-7% of the average annual rainfall. Isn't this range a little narrow considering that the datasources are satellite based data and global land data assimilation model outputs? In the cited study by MacDonald et al 2021, who synthesised recharge rates in arid africa based on more local and therefore generally more accurate methods for the studied regions, assume recharge rates of 3.3 +/- 5.5% of the annual average rainfall and thereby provide a more conservative range of ~0-10%. What I want to say is that I believe that the uncertainty estimates are too small and neglect some intrinsic uncertainty in the source products used for these calculations. This being said, I believe that the order of magnitude of the estimated recharge is very reasonable. To conclude, I expect that the authors add a thorough discussion of how reasonable these uncertainty estimates are given the uncertainty in the source products and the applied method.

- Lines 191-193: Related to the above comment, rather than just assuming that unquantified outlets constitute minor outflows and then neglecting them, I suggest considering the impact of such outflows along the boundaries of the system quantiatively by adding a term to the water balance and extending the uncertainty analysis. This can be done very quickly and would put a number on that assumption, rather than neglecting such terms. The beauty of a simple water balance analysis is that such terms can easily be considered qualitatively. This could provide yet more realistic uncertainty estimates and help in resolving the aforementioned issue.

- I miss a discussion of the importance of ephemeral and intermittent streams in arid regions. These are often the main sources of recharge in arid regions as they collect and distribute the rainfall rapidly throughout the system, making infiltration available also to regions where it didn't rain locally. As stated in the beginning of section 2.4, permanent surface water bodies are almost completely absent from the Saq-Ram aquifer system, but surely intermittent systems are not. In other words, what happens to all the rainfall that doesn't form recharge prior to it being evaporated or transpired (i.e., ~95% of the AAR, according to the calculations in this study)? Before that water evaporates or is consumed and transpired by vegetation, it certainly forms intermittent stream networks. I suggest adding a short paragraph on their importance for (eco)hydrology and especially groundwater recharge in arid regions, supported by the at least the three references listed below, and drawing a link to intermittent streams on the arabian peninsula and the Saq-Ram Aquifer system. This would nicely round off the discussion of the importance of artificial recharge from agriculture and of the geology on the regional recharge. Suggested references:

Bourke et al., 2020, doi: 10.1002/wat2.1504
Dogramaci et al., 2015 , doi: 10.1016/j.jhydrol.2014.12.017

- Lines 270-273: This is not well explained and it's completely unclear to me which polygons were used to spatially average the GRACE and GLDAS products over the studied domain. In Figure 3, which is referenced here, no polygons or maps are provided. Explain.

Figures:

- Figure 1: provide coordinate reference system

- Figure 2: from the legend and the caption it is not clear what the different lines refer to. Extend the caption to provide more information than just references without any additional info. It should be clear from the caption alone what is meant, the reader should not have to go and dig through the manuscript for the explanation of those references first.

- Figure 3: Change axis titles to all lower case titles or use the already introduced abbreviations right away.

- Figure 7: A very nice analysis and presentation

Abbreviations:

- The Kingdom of Saudi Arabia (KSA) is sometimes called 'Saudi Arabia', sometimes with the abbreviation KSA or sometimes simply referred to as 'Saudi'. Double check and make the naming consistent throughout the manuscript.

- The GRACE abbreviation is introduced at least three times: once in the abstract, once in the intro, once in the methods. Introduce it once in the intro, that is sufficient. Remove the introduction of the abbreviation in the abstract to save space for more relevant info.

- Other abbreviations such as terrestrial water storage (TWS), GWS and SWS are also introduced multiple times (three or four times at leas). Moreover, the full names are written with capital first letters in the figures' axis titles (e.g, Figure 3), rather than without capital letters or with the abbreviations. Avoid introducing abbreviations so many times and make the naming consistent throughout the manuscript.

References:

- The intro is a little light on recent references, particularly on available methods for groundwater recharge quantification (in arid regions). Since all methods are subject to different sources of considerable uncertainty, it would be good to provide more references and to direct the reader to this information. I would suggest adding the following references to lines 62-65:

Shanafield and Cook, 2014, doi: 10.1016/j.jhydrol.2014.01.068
Banks et al., 2020, doi: 10.1016/j.jhydrol.2020.125753

- For the discussion of the importance (and dominance) of intermittent streams on groundwater recharge in arid regions, see comment above

- Lines 249-252: provide a reference for this statement