Our answers in *Italic*.

Reviewer #1 Evaluations:

Thank you for submitting your Manuscript to HESS. Please find below the comments and suggestions made regarding the current version of the manuscript.

This manuscript aims to study the influence of topography on the desaturation rates of groundwater-dependent landscapes in response to changes in recharge. The authors achieve this objective by categorizing the catchments into lowland, transition, and mountain settings clusters, using geomorphon descriptors, and implementing 3D steady-state groundwater models to derive each catchment's flow partitioning and seepage area extent. The findings illustrate that mountains exhibit reduced seepage area compared to lowlands at equivalent hydraulic conductivity and recharge ratios but are less sensitive to fluctuations in recharge. Finally, the authors performed a correlation statistical analysis between the geomorphon-define landforms and the desaturation indicators, which, according to them, enables the prediction of sensitivity to climate change based on topographic analysis.

I have read the manuscript with great interest. My overall opinion is that the manuscript is well-written but needs some moderate revisions and clarifications. Below, I have listed comments, hoping they may help improve the manuscript's quality.

We would like to thank the reviewer for the interest shown in our work and for the constructive evaluation. We appreciate the recognition of our modelling approach and the valuable suggestions provided to improve clarity. All comments will be carefully addressed and incorporated into the revised manuscript.

Specific Comments

1. Some clarification is needed regarding the 3D numerical model approach.
    1. The authors extended the model domain by 20% of the total area of the catchment to avoid boundary effects. In the extended domain, did the authors use the elevation of adjacent catchments? Have the authors considered possible interbasin flow happening among catchments, as described in Fan (2019)? If so, are there any implications for this interbasin flow in the general results for lowland settings?

Indeed, the elevation of the adjacent catchments was used. Recharge was applied on all model cells, including the buffer area around the catchment, while the catchment is in the center of the simulated area. The 60 modeled catchments and their boundaries were validated by analyzing the topographic context in the area (topographic maps of each catchment and its buffer zone will be added to the repository in an effort to improve visualization and transparency of the modelled area). Considering this approach and the wide range of saturation studied (from full saturation to < 1%), the catchment imports and exports water from neighboring catchments, but the buffer area guarantees a limited effect of the boundary on the catchments of interest. With that in mind, the purpose of the paper was not to trace recharge inside and outside the catchment but to observe the behavior of seepage area in the catchment. We will improve the description of the buffer zone and its impact on interbasin flow in section 2.3 detailing the numerical modelling approach.

2. To simplify the analysis, the authors assumed an aquifer thickness of 100 meters for all catchments with a homogeneous and isotropic hydraulic conductivity. Although these assumptions ease the comparison of these systems, there are some limitations that need to be addressed. For instance, what are the values of hydraulic conductivity used for each catchment? did the authors calculate an equivalent hydraulic conductivity for each catchment using the geology of each site? Also, the depth to bedrock may vary within each catchment depending on the geology; could these changes affect the seepage calculations? Lastly, it has been suggested that meteoric water can travel to depths of kilometers in areas with high topographic relief (i.e., Frisbee et al., 2017; McIntosh & Ferguson, 2021). Have the authors considered that some of the flowpaths that contribute to seepage or that export to other catchments could come from these deep groundwater systems? I suggest including these limitations within the manuscript to aid in discussing the results.

In this study, we do not aim to model the impact of specific-site geology and local heterogeneity. We only use the topographies of the Chilean landscapes for their diversity in landform shapes. It is a synthetic study that aims at extracting scaling laws between landforms, and groundwater seepage distribution. Thus, we did not assign site-specific K values nor calculate equivalent hydraulic conductivities based on local geology. Neither did we consider complex patterns of recharge. Instead, we investigate the impact of topographies over a wide range of values of the dimensionless ratio K/R, covering from humid to arid systems, from hard-rock to sedimentary environments. We may recall as well that analytical solutions to the diffusivity equation in unconfined conditions reveal that the piezometric level is directly controlled by the K/R ratio, indicating the pertinence of the K/R ratio for studying the surface-subsurface interaction and seepage area development.

We will revise the manuscript to clearly state these assumptions and discuss their implications, particularly in the context of extrapolating our findings to natural systems with complex geology and flow systems operating at multiple scales. We propose to include in Figure 3 the climatic-geological context along with the horizontal axis (K/R ratio).

3. Similarly, the authors assumed a uniform effective recharge for all the catchments. Did the authors assume probable recharge ranges for the area of study or arbitrarily pick recharge values to explore a wide range of *K/R* that presented desaturation? I recommend clarifying this part in the text.

As mentioned before, we chose to investigate a wide range of K/R to obtain the full range of possible saturation for each catchment consistently with various climatic contexts (humid, semi-arid, arid). Furthermore, to consider more realistic settings in terms of K/R, the fit on the desaturation function was weighted for seepage values < 20%. We will clarify that:

- *The fit has been carried out on the possible saturation range in the text.*
- *The K/R ratio covers plausible climatic and geological contexts in Figure 3.*

4. This reviewer understands that this might be out of the scope of the study. However, the authors focused on the dimensionless ratio between hydraulic conductivity and recharge (*K/R*). This dimensionless quantity comes from previous studies done on 1D and 2D analysis (e.g., Bresciani et al., 2014). Have the authors considered doing a

dimensional analysis of their 3D model to explore what other dimensionless quantities arise from a catchment scale system? There might be other dimensionless quantities that relate aquifer thickness and drainage length, allowing another physical approach to relating the studied catchments.

Identifying additional scaling that integrates more fully the 3D nature of groundwater flow systems, and the influence of topographic metrics is interesting. Although we did not perform a full dimensional analysis in this study, we recognize the value of such an approach but it falls beyond the scope of this study. To the knowledge of the authors, there are no analytical solutions to support a 3D dimensional analysis. We will include a note in the discussion acknowledging this potential and the opportunity it presents for further research.

2. In line 157, within the results section, the authors state: "The fit shows minimal RMSE values between 0.01 and 0.08, indicating that seepage evolution with increasing K/R can be successfully parameterized with only two parameters, λ and n." These results come from the multiple assumptions made to the conceptual model. Have the authors considered if this conclusion will hold if the analyzed system is heterogeneous and anisotropic or if the thickness of the aquifer is variable within the system? Some of these thoughts can be addressed as possible limitations of the study.

Thank you for this comment. Following on the previous comments and answers, we will make sure to discuss more in depth the applications and limitations of our results in the discussion, with an emphasis on the potential impacts of heterogeneous and anisotropic cases.

3. By the end of the results section, starting in line 216, the authors briefly explain how they fitted a Random Forest model to predict the values of λ and n in other catchments based on PCA analysis of the topographic parameters. I suggest moving and expanding this explanation to the methods section, as it will aid in understanding the reasoning behind performing such an analysis.

We agree - the detailed explanation about our Random Forest algorithm and study will be moved to the method sections.

4. This analysis shows that some predicted catchments are clustered as lowland catchments (red contours) despite being located within the Andes Cordillera (Figure 4d at the northern part of the map). Are these correctly labeled? Are these there because they are located in flatter places within the Cordillera? Or are these outliers from the analysis? I suggest adding more information about these possible outliers.

These catchments are indeed well labeled as lowland catchments based on their landforms description (mostly flat), those catchments correspond to Altiplano, and endoreic catchments located in the Cordillera explaining their labelling. However, we agree with the reviewer that the term "lowland" in not appropriate in this case. Then, we propose to modify the cluster name from "lowlands" to "flat" to avoid confusion and will add detailed comments to the discussion section specifically on Altiplano flat catchments.

5. Based on the previous comments, I suggest including an additional paragraph or section that addresses the study's potential limitations. This addition can help describe the implications of these findings and the future work needed to address some of the assumptions.

We agree with the reviewer and will add and discuss potential limitations of our study.

Technical Corrections

Besides the comments described above, I have a few technical recommendations for the manuscript.

1. Line 27 states: “Considering steady-state groundwater flow systems, the depth of the water table, **and so the** distribution of flow paths…” Consider removing “so.”

The “so” will be removed.

2. In lines 77 and 139, there is a reference to Figure 1a and Figure 1c, arguing that this figure shows the catchment colors and clusters. However, there is no reference to the colors and clusters in Figure 1. This might be missing from the figure, or the authors might reference Figure 4 instead. Please verify this inconsistency.

The reference to the figure will be corrected.

3. I suggest changing the equation numbering to “(1)” instead of “Equation 1.”

The equations numbering will be modified.