Response to Reviewer #2 Comments:

General Comments

This study demonstrates an integrated remote sensing framework for improving the understanding of long-term reservoir storage dynamics at the global scale. The methods of this study highlight a combination of well-established quantitative approaches and publicly available data sets and have the potential to benefit studies across water resources management and satellite remote sensing. The manuscript is well written and organized, but further explanation or clarification might be needed on the hydrology part, particularly for some components of trend analysis and associated conclusions.

We thank the reviewer for the thoughtful comments and constructive suggestions, which will help us to improve the quality of the manuscript. Below please find our response to reviewer's comments in detail.

Specific Comments

R2C1) My major concern is that the trend analysis didn't include reservoir outflow and water use at the reservoir or basin level. The authors did attempt to explain the lack of data behind their decision, but this may not be sufficient to justify an incomplete analysis of the reservoir water balance. Without a reasonable estimation of the dynamics of outflow and water use, it is not convincible that the trend in precipitation/stemflows alone can effectively explain the trend in reservoir storage, particularly for those reservoirs where the trends in precipitation/streamflow and storage are not consistent. Therefore, some of the conclusions on the influence of water use are not robust, e.g., lines 17-18, 221-223, 248-249, 267-268, 362-365, and 376-377.

We thank the review for this comment. Attributing the causes of reservoir storage change is at the same time important and challenging. There are no water demand and supply or dam operation data available globally (and even very hard to come by locally), and so we are not able to access the influence of human activities on reservoirs directly using such data. Instead, the underlying principle of this study is that the water volume dynamics in a reservoir are the net balance of inflow (streamflow, driven by precipitation), net evaporation (i.e., evaporation minus direct precipitation) and reservoir releases. Based on this, we analysed the individual terms inflow (temporal correlation) and net evaporation (trend ratio in volume) and then, where possible, deduced the role of dam water releases as a residual. This indirect method is the only approach possible given lacking water release data, but by applying logic to the result we were still able to make insightful deductions.

Thus, for the majority of the 65 basins with significant storage changes, trends were of the same sign for storage, runoff and precipitation (Fig.7; L269-271). If rainfall and runoff trends show the same directions as reservoir storage, then it is most plausible that climate variations play an important role in reservoir storage trends. On the other hand, if rainfall/runoff and reservoir storage show <u>opposite</u> trends, would that constitute evidence that either direct evaporation or water releases are the driving process, and we were able to exclude the former as a driving

process. We propose that this logical framework is very robust but welcome arguments as to why it might not be.

There are other recent studies that come to similar conclusion about the limited impact of water releases. For example, Wang et al. (2017) found that climate variability was the dominant driver of the decreasing area trend of lakes across China's Yangtze Plain while human activities only accounted 10-20% of these lake changes, even though the Three Gorges Dam was constructed upstream. Yang et al. (2021) demonstrated that climate variations dominate flood changes in China although there are more dams constructed and land use has changed. We will include such additional evidence in the revised manuscript.

Summarising, we agree with the reviewer that we do not have direct evidence on reservoir releases (or water use) and thereby some of the conclusions on this front are not as robust as we might have liked. Nonetheless, we argue that our interpretation is coherent and logical and still provides insightful evidence. We will however temper the relevant statements to acknowledge the indirect nature of our evidence, for example in L17-18:

> "*Many of the observed reservoir changes were explained well by changes in precipitation and river inflows, emphasising the importance of multi-decadal precipitation changes for reservoir water storage. The results also indicated that there is little impact of changes in net evaporation on storage trends. A more definitive conclusion about any contribution of changes in water releases at global scale would require data that are currently not shared, but we deduce it is unlikely that water release trends dominate global trends.*"

in L248-249:

> *"If precipitation and runoff trends show the same direction as reservoir storage trends, then it is plausible that climate variations play an important role in reservoir storage trends. On the other hand, if rainfall and runoff show opposite trends to those in reservoir storage, then that could suggest evidence of a dominant influence from either net evaporation or water releases. For the majority of these 65 basins, trends were of the same sign for storage, runoff and precipitation, suggesting that precipitation changes are ultimately the most likely explanation for observed trends (Fig. 7a and b)."*

in L362-365:

> *"Both lakes and reservoirs are influenced by changing inflow and net evaporation in response to climate variability. Although human regulation has more influence on reservoirs than on natural lakes, our results suggest that for the majority of basins natural influences dominate human impacts, although these may still exist. For example, Cooley et al. (2021) found that human interventions have resulted in larger seasonal variability in reservoirs than that in lakes globally."*

in L374-377

> *"Given that reservoir storage dynamics are the net result of river inflows, net evaporation and*

dam water releases, we found a reasonably strong relationship between changes in river flow and reservoir storage, while changes in net evaporation do not seem to have affected storage trends significantly. We infer that human activities, and specifically reservoir releases, are less likely to be the dominant driver of three-decadal trends in reservoir storage, but acknowledge that our evidence for this conclusion is of an indirect nature, and would require corroboration for an individual reservoir using actual release data"

[1] Wang, J., Sheng, Y., & Wada, Y. (2017). Little impact of the Three Gorges Dam on recent decadal lake decline across China's Yangtze Plain. Water Resources Research, 53(5), 3854-3877.

[2] Yang, L., Yang, Y., Villarini, G., Li, X., Hu, H., Wang, L., Blöschl, G. & Tian, F. (2021). Climate More Important for Chinese Flood Changes than Reservoirs and Land Use. Geophysical Research Letters, 48(11), e2021GL093061.

[3] Cooley, S. W., Ryan, J. C., & Smith, L. C. (2021). Human alteration of global surface water storage variability. Nature, 591(7848), 78-81.

R2C2) The analysis of reservoir reliability, resilience, and vulnerability (lines 172-189) is a good extension to the estimated reservoir storage dynamics. The concepts and calculations in this part could be better introduced by using a real reservoir as an example, perhaps a well-known reservoir with good data availability. Also, how did the authors determine the time length of failure events (line 178) determined? How does the value of this factor vary among different reservoirs or basins? What is the unit of resilience (line 185)?

We thank the review for this suggestion. The time length of failure event is defined as the number of continuous months when the storage level drops below 10% lowest value (please see "Duration Time (month)" in Table 3). The time length of failure event is converted to the resilience index using the Eq.6 (L185) from to the previous studies (Hashimoto et al. 1982; Kjeldsen and Rosbjerg 2004). The resilience index ranges from 0 to 1 and has no unit. The lower index it is, the slower recover rate (weakened resilience) the reservoir has, and vice versa. We will include a real reservoir as an example to introduce reliability, resilience, and vulnerability (Fig.3 and Table 3).

R2C3) Field observations and modeling studies have shown that evaporative loss from reservoir surface can be quite significant, especially for reservoirs in arid and semi-arid regions. This seems to be contradictory to some conclusions from this study (lines 265-266, 307-308 and 311).

Thank you for this comment. We agree that evaporative losses from reservoirs are large in some arid and semi-arid regions. However, firstly, evaporative losses are relatively more significant in small reservoirs (Mady et al., 2020). Secondly, large evaporative losses affect seasonal storage dynamics but this does not necessarily mean that trends in evaporation explain a long-term trend in reservoir storage. We will include this in the revised manuscript. In addition, we will add the validation of trend analyses of net evaporation against Zhao and Gao (2019), referring to our response to R1C3 for full details (the second paragraph).

[4] Mady, B., Lehmann, P., Gorelick, S. M., & Or, D. (2020). Distribution of small seasonal

reservoirs in semi-arid regions and associated evaporative losses. Environmental Research Communications, 2(6), 061002.

Technical Corrections

R2C4) Figures 2-3. No need to use the second y-axis.

We will change it to use the same vertical scale

R2C5) Line 171. Remove the comma.

We will remove the comma in this sentence.

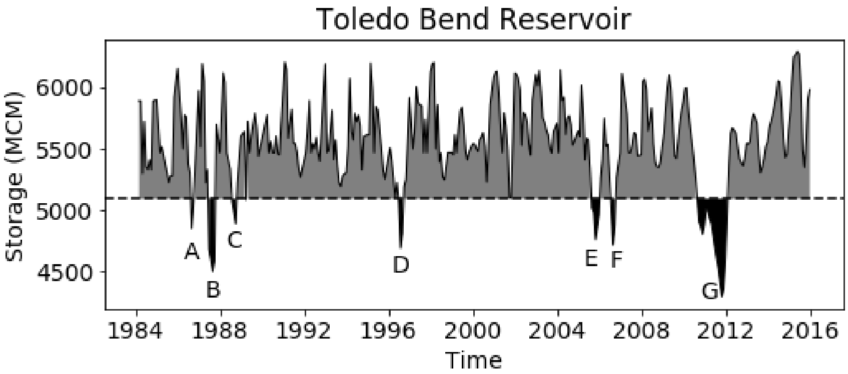

Figure 3 Example storage time series showing the definition of resilience and vulnerability (black shade: unsatisfactory state; grey shade: satisfactory state, black line: temporal storages; dash line: 10% threshold; letters: failure events).

Table 3 The statistics of resilience and vulnerability for the reservoir in Fig. 3.

Period	1984-2000				2000-2015		
Failure Event	A	B	C	D	E	F	G
Duration Time (month)	2	4	3	3	5	3	18
Resilience (1/average duration)	0.33				0.12		
Deficit Volume (GL)	239	589	202	399	329	373	792
Vulnerability (average deficit volume)	357				498		