Peer Review File

Current availability and distribution of Congo Basin's freshwater resources

Web links to the author's journal account have been redacted from the decision letters as indicated to maintain confidentiality

28th Jul 22

Dear Dr. Tourian,

Please allow us to sincerely apologise for the delay in sending a decision on your manuscript titled "Current availability and distribution of Congo basin's freshwater resources". It has now been seen by 3 reviewers, whose comments are appended below. You will see that they find your work of some potential interest. However, they have raised quite substantial concerns that must be addressed. In light of these comments, we cannot accept the manuscript for publication, but would be interested in considering a revised version that fully addresses these serious concerns.

We hope you will find the reviewers' comments useful as you decide how to proceed. For publication of a revised manuscript in Communications Earth & Environment to be appropriate, we would need you to:
• Examine the impact of uncertainty resulting from other sources, such as altimetry stations, on the analysis.
• Provide sufficient method details that the work could be replicated by an independent researcher.
• Clarify the omission of wetland storage for estimating the drainable water.
• Discuss the impacts of wetland storage, either as a separate storage entity or as a part of a lake if there is connectivity between the two.
• Provide support for interpretations and claims through the analysis of the data.

Should additional work allow you to address these criticisms, we would be happy to look at a substantially revised manuscript. If you choose to take up this option, please either highlight all changes in the manuscript text file, or provide a list of the changes to the manuscript with your responses to the reviewers.

Please bear in mind that we will be reluctant to approach the reviewers again in the absence of substantial revisions.

If the revision process takes significantly longer than three months, we will be happy to reconsider your paper at a later date, as long as nothing similar has been accepted for publication at Communications Earth & Environment or published elsewhere in the meantime.

We understand that due to the current global situation, the time required for revision may be longer than usual. We would appreciate it if you could keep us informed about an estimated timescale for resubmission, to facilitate our planning. Of course, if you are unable to estimate, we are happy to accommodate necessary extensions nevertheless.

We are committed to providing a fair and constructive peer-review process. Please do not hesitate to contact us if you wish to discuss the revision in more detail.

Please use the following link to submit your revised manuscript, point-by-point response to the reviewers' comments with a list of your changes to the manuscript text (which should be in a separate document to any cover letter) and any completed checklist:

[link redacted]

** This url links to your confidential home page and associated information about manuscripts you may have submitted or be reviewing for us. If you wish to forward this email to co-authors, please delete the link to your homepage first **

Please do not hesitate to contact me if you have any questions or would like to discuss the required revisions further. Thank you for the opportunity to review your work.

Best regards,

Rahim Barzegar, PhD
Editorial Board Member
Communications Earth & Environment
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Joe Aslin
Locum Chief Editor
Communications Earth & Environment

EDITORIAL POLICIES AND FORMAT

If you decide to resubmit your paper, please ensure that your manuscript complies with our editorial policies and complete and upload the checklist below as a Related Manuscript file type with the revised article:

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For your information, you can find some guidance regarding format requirements summarized on the following checklist:(https://www.nature.com/documents/commsj-phys-style-formatting-checklist-article.pdf) and formatting guide (https://www.nature.com/documents/commsj-phys-style-formatting-guide-accept.pdf).

REVIEWER COMMENTS:

Reviewer #1 (Remarks to the Author):

Review of ”Current availability and distribution of Congo basin’s freshwater resources.”

Summary: This study quantifies the water availability in Congo Basins using the storage-discharge relationship. The estimated potential drainable water storage is 481 km3 and an average residence time of 4.3 months. The methodology used is based on their previous publications. In this paper, they apply it to Congo river basins. Overall, I think this research has significant impact and advance in the quantification of water resources. I recommend a minor revision since there are a few things that I would like to get clarified.

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Major Comment:

1.Justification of using DWSA instead of TWSA in the main text: I don't fully understand why lake needs to be decoupled from TWSA as DWSA. If DWSA is used, does lake outflow need to be removed from the river discharge?

In other words, the lake itself can also have a lake-storage-to-lake-outflow relationship. It might be challenging to get the outflow, but what is your comment on the lake resistance (time)? Will that be longer than 105.8 months for Lualaba-Lukuga?

2.Uncertainties from altimetry station: The authors have a good discussion on the uncertainties on pages 13-14. How about the uncertainties from the locations of stations? From Figure1, the locations of the altimetry are not always at the outlet of the sub-basin. If the rating curve is to fit the water level from a location to the discharge of another location, how is that going to affect the results? Can the authors also list the total drainage area in Table S2?

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Minor comment:

1.I think Figure S4 needs to be in the main text. Could you replace Figure 3 bottom right with Figure S4?

2.Some variables are in volume, and some variables are in height in Table2. If different units must be used, could authors also list the sizes of two basins as well?

3.Contribution from the groundwater: Could the different results of the sub-basin explain by the locations of the groundwater aquifers?

4.Figure 5: instead of the minimum anomalies, could authors show the range of TWS, which is more intuitive?

Reviewer #2 (Remarks to the Author):

The manuscript attempts to address a timely assessment of water resources in an understudied region. The approach seems novel; however, the approach is not clear and lacks details. The Material and Methods section needs significant revisions. The authors should keep in mind this section should pass the reproducibility test. If adequate details cannot be included in the main text, please add them in the SI. The authors have also failed to adequately summarize recent work in the Congo River Basin. Several publications are suggested below.

I have provided detailed comments below. In addition, I would also like the authors clarify the following. The estimation of drainable water storage is estimated based on GRACE, historical flow records and altimetry data. The GRACE storage anomalies include canopy and soil storage, lakes, wetlands and groundwater. The altimetry data is available only for large rivers. The analyses use only lake storage to estimate drainable water storage. Given that nearly 50% of the river basin area is under tropical rainforest and the presence of wetlands that exert significant control on drainage, can the authors justify the use of lake only to estimate drainable water? Can they show or justify that ignoring other storage anomalies will not alter the drainable water estimates?

1. Overall, the figure captions do not adequately explain what is presented in the figure and are ambiguous. The period of analysis and spatial and temporal resolutions are not mentioned in the text (Data and Methods or in SI). This is another key weakness in the manuscript.

2. The reference numbers appear out of order; #44 appears first, whereas #1 appears in page 15.

3. Paragraph 1: Authors have not acknowledged several contributions on climate and water resources. I have highlighted several below. None of the IPCC reports, which have highlighted the current state of science and research needs, have been cited.

a. Simulated hydrologic response to projected changes in precipitation and temperature in the Congo River basin - (1).

b. Data-driven estimates of evapotranspiration and its controls in the Congo Basin - (2).

c. Evaluation of historical and future simulations of precipitation and temperature in central Africa from CMIP5 climate models - (3).

d. Contrasting controls on Congo Basin evaporation at the two rainfall peaks - (4).

e. The Relationship of Rainfall Variability in Western Equatorial Africa to the Tropical Oceans and Atmospheric Circulation. Part I: The Boreal Spring - (5).

f. The Relationship of Rainfall Variability in Western Equatorial Africa to the Tropical Oceans and Atmospheric Circulation. Part II: The Boreal Autumn - (6).

g. Rainfall and temperature variations over Congo-Brazzaville between 1950 and 1998 - (7).

h. Balancing hydropower and biodiversity in the Amazon, Congo, and Mekong - (8).

i. Fragmentation and Flow Regulation of the World's Large River Systems - (9).

j. Water Issues in the Democratic Republic of the Congo: Challenges and Opportunities (10).

4. Main objectives (paragraph 3): objective 2 is not clear – resistance to what? Objective 3 is too vague. There are several studies, since the 1960s, that have quantified available and accessible water resources. What are the new insights – please be specific.

5. (Section mentioned in Results - Water storage-discharge relationship)

The control lakes and wetlands exert on water storage and flow regulation has been well documented (e.g., see Alsdorf et al., (11) http://dx.doi.org/10.1002/2016RG000517, and Aloysius and Saiers (1) https://doi.org/10.5194/hess-21-4115-2017). Authors have recognized this in the discussion section. These controls are prominent in the Lualaba-South and Kasai. I also want to emphasize that Kasai sub-basin does not have larger lakes as the Lualaba-South or the Lualaba-Lukuga. Thus, the generalization that lakes exert control over flows and storage is a weak argument. Alsdorf et al., citing several studies, highlight the wetlands' control on storage and flows can be significant as lakes.

Note that Lake Tanganyika is an outlier, and in most cases the outflow is nearly equal to the inflows. Authors should recognize these and update relevant sections including Methods and Materials.

Overall, I think the following questions should be answered or clarified. Would the results be different if wetland storages are included in the analysis (a) as a separate storage entity or (b) included as part of the lake if there is connectivity?

It appears that authors have only considered larger lakes that have reported values for … Overall, the ratio of LWSA to TWSA for the Congo Basin is about 10% (Figure 2 bottom), but with regional differences, from 5% in Kasai, 15% in Lualaba-South to 60% in Lualaba-Lukuga… → As I mentioned elsewhere, the Lualaba-Lukuga is an outlier. Published work and water balance studies reveal that Lake Tanganyika alone exert significant control over outflows (see (12, 13) and other references). Authors should recognize and acknowledge these facts. Generalizing results based on high LWSA/TWSA ratios may lead to biased overall conclusions.

Authors use LWSA to estimate DWSA and ignore the contribution of wetlands. The GRACE estimates also include soil water and canopy storage. Given that nearly 50% of land cover is dense tropical rainforest and water bodies occupy ~3% of the catchment, can authors confirm that the influence of water stored in (i) forest canopy, (ii) soils and (iii) wetlands are negligible? These are major weaknesses in this study. Authors should clearly establish that ignoring the wetlands will not change the results and conclusions. Authors acknowledge the importance of wetlands elsewhere when they describe "basin resistance", however, they ignore the importance in the analysis.

Many interpretations in paragraph 1 in page 7 are not supported by the analysis. If they indeed are, please clarify. For example, I am finding it difficult understand how the statement "…the drainage of Middle Congo, Lualaba-South and Lualaba-Lukuga appears to occur with a faster rate…" is supported by the analysis presented here. There several instances like this. AGAIN, without considering the influence of wetlands, and solely based on estimates of lake storage anomalies, this estimate is not closer to the true values. For context, could the authors provide how the estimate (481 ± 24 km3) compare with runoff/rainfall ration (~0.4) for the Congo. By the way, are these annual values?

The comments below are related to sections in the Materials and Methods, which the authors have mentioned in the Results section.

a. Total Water Storage Anomaly from GRACE: The description is too abstract. Please expand and clarify – C20, C30, degree 1, destriping filter, why the corrections are needed for tidal aliasing error, what is GIA and why this adjustment is needed? Most of all, why are the authors not using the published GRACE products? It's not clear if the data are derived by the authors or they are using published data products (NASA, JPL). The spatial and temporal resolutions, period of analyses are not provided.

b. Lake water storage anomaly: this section fails the reproducibility test. With the information given, it will be extremely difficult even for an expert to reproduce the results.

c. River discharge: The rating curves are based on 1950-59 stream flow data (estimated based on water depth, if you look at the original data report) and present day (which years and temporal resolution ???) altimetry data. Briefly explain how flow rates are estimated or include the brief in SI. Please also confirm that the precipitation patterns during the present-day and 1950-59 periods are not significantly different.
Include all the relevant citations.

d. Methodology: Briefly explain the methods used to calculate water storage anomaly and discharge; elaborate further "… Due to its complexity and very different characteristics…"; This section does not provide any information about how the fluxes are calculated other than citing references (31, 36 and 30). This should be expanded and explained further in details in the SI.
Same comment for "Estimation of Total Drainable Water Storage and basin resistance" section ass well.

e. SI – S1: Methods section and Table S1 does not state how the data are acquired. Are they based on observed values? If yes, are they for the analyses period 2002-2018? Either in "Methods" section or under SI – S1, authors should provide the methods used to estimate water storage anomaly and discharge; merely stating they followed (31, 36, 30) is not adequate.

f. SI – S3: briefly explain how the sources of data used to estimate lake volumes and storage anomalies. As it is, the details are not sufficient to reproduce the results presented in the analysis. Did the authors use all the lakes in the sub-basins identified in Figure 1? If selected lakes are used, then include the details in a table in SI.

g. SI – S5: the period of analysis is 2002-2018. Please clarify as to why the precipitation plots are for 1891-2019. How are these data and at what spatial/temporal-scale used in the analysis?

6. Congo versus Amazon (page 11): The comparison here makes sense and is plausible. However, the analyses, interpretation and discussion do not convince nor conclusively support the facts presented here.

References

1. N. Aloysius, J. Saiers, Simulated hydrologic response to projected changes in precipitation and temperature in the Congo River basin. Hydrol. Earth Syst. Sci. 21, 4115-4130 (2017).
2. M. W. Burnett, G. R. Quetin, A. G. Konings, Data-driven estimates of evapotranspiration and its controls in the Congo Basin. Hydrology and Earth System Sciences 24, 4189–4211 (2020).
3. N. Aloysius, J. Sheffield, J. E. Saiers, H. Li, E. F. Wood, Evaluation of historical and future simulations of precipitation and temperature in Central Africa from CMIP5 climate models. Journal of Geophysical Research - Atmospheres 121, 130-152 (2016).
4. D. Crowhurst, S. Dadson, J. Peng, R. Washington, Contrasting controls on Congo Basin evaporation at the two rainfall peaks. Climate Dynamics 56, 1609-1624 (2021).
5. S. E. Nicholson, A. K. Dezfuli, The Relationship of Rainfall Variability in Western Equatorial Africa to the Tropical Oceans and Atmospheric Circulation. Part I: The Boreal Spring. Journal of Climate 26, 45-65 (2013).
6. A. K. Dezfuli, S. E. Nicholson, The Relationship of Rainfall Variability in Western Equatorial Africa to the Tropical Oceans and Atmospheric Circulation. Part II: The Boreal Autumn. Journal of Climate 26, 66-84 (2013).
7. G. Samba, D. Nganga, M. Mpounza, Rainfall and temperature variations over Congo-Brazzaville between 1950 and 1998. Theoretical and Applied Climatology 91, 85-97 (2008).
8. K. O. Winemiller et al., Balancing hydropower and biodiversity in the Amazon, Congo, and Mekong. Science 351, 128-129 (2016).
9. C. Nilsson, C. A. Reidy, M. Dynesius, C. Revenga, Fragmentation and Flow Regulation of the World's Large River Systems. Science 308, 405-408 (2005).
10. UNEP, "Water Issues in the Democratic Republic of the Congo: Challenges and Opportunities," (United Nations Environment Program, Nairobi, Kenya, 2011).
11. D. Alsdorf et al., Opportunities for hydrologic research in the Congo Basin. Reviews of Geophysics 54, 378-409 (2016).
12. L. Bergonzini, in The Issyk-Kul Lake: Evaluation of the Environmental State and Its Remediation, J. Klerkx, B. Imanackunov, Eds. (Kluwer Academic Publishers, 2000).
13. S. E. Nicholson, Historical and modern fluctuations of Lakes Tanganyika and Rukwa and their relationship to rainfall variability. Climatic Change 41, 53-71 (1999).

Reviewer #3 (Remarks to the Author):

The authors of the manuscript entitled “Current availability and distribution of Congo basin’s freshwater resources”, tried to estimate drainable water storage (TDWS) of the Congo basin, indicating that it currently holds ~ 480 km3 of water unevenly distributed throughout the basin. The authors also estimated the time constant for draining its entire water storage to be ~ 4.3 months. Some insight into Congo’ water resource availability is provided.

Overall, the authors characterized water storage changes and the relationship between river discharge and TDWS over the Congo basin. A lot of numbers on this characterization have been presented. The authors compared these numbers with FAO-based renewable groundwater storage changes and those for the Amazon given by other studies. Unfortunately, this characterization does not seem to provide process-based understanding of changes in the hydrology and its ecological, environmental, and/or climatic consequences/feedback for the vast region of the African continent. Also, the methods used by the authors are quite standard, mostly reliant on GRACE observations and some publicly available altimetry/optical image-based data sets that are built on the work conducted previously. I feel that this study might not reach the standard of publication in Communications Earth & Environment, though Communications Earth & Environment does not have such a high standard of Nature Communications, which I clearly note. This study might be more suited to a specialized journal outlet.

Regarding the presentation, overall, it is good. But I note that the authors use a couple of paragraphs detailing the limitations of this study in the discussion section. This reads like the narratives that mostly occur in a specialized journal. Figures 1-2 are not quite informative. Figure 1 presents basic information on the geography of the Congo basin. Figure 2 shows total water storage changes from GRACE and GRACE Follow-On, and lake water storage changes from satellite altimetry over the Congo basin and its subbasins. I believe that these figures should be put in the Supporting Information.

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10.10.2022

Revised manuscript by Tourian et al

Dear Reviewers,

Please find enclosed our responses to the assessment of the manuscript entitled "Current availability and distribution of Congo basin's freshwater resources" that we submitted as a contribution to *Communications Earth & Environment*.

We are very grateful for your careful assessment of our study, for your constructive comments and for the questions you have raised. We have given full attention to all comments and suggestions and made all revisions accordingly. It has resulted in an improved manuscript that fully addresses all concerns. We hope it is now suitable for publication.

With respect to the revision of the manuscript, the following major changes have been done:

- **Quantifying water storage in wetlands:** we fully agree with reviewers' comments regarding the contingent resistance in the drainage system from wetlands. In the first version of the manuscript, this was acknowledged in the "Limitations" section, where the estimates based on the Total Water Storage Anomaly (TWSA, i.e. without any decoupling) were given as upper limits. However, after reading reviewers' concerns and feedback on that matter, we have decided to also quantify Wetland Water Storage Anomaly (WWSA), along with the Lake Water Storage Anomaly (LWSA), and remove both components from TWSA. Therefore, numbers, but also interpretations and discussions have been updated in the revised manuscript.

- **Providing sufficient detail of the methodology**: The revised manuscript contains sufficient methodological details to ensure reproducibility of the developed algorithms and results. We believe that with such details in the data used and the methods, the work could now be replicated by an independent researcher
- **Additionally**: we have also answered questions regarding the impact of uncertainties on the analysis, resulting from other sources such as altimetry stations, and we have paid attention to improve our interpretations and claims through the analysis of the data.

With respect to the detailed responses to your comments, your assessments appear below in black and we highlighted our answers in blue. We are providing detailed answers with additional figures to improve the readability of the rebuttal. We believe we have addressed each comment carefully and hope that the responses meet your expectations.

Best Regards,

Mohammad J. Tourian, on behalf of all authors

Reviewer #1 (Remarks to the Author):

Review of "Current availability and distribution of Congo basin's freshwater resources."

Summary: This study quantifies the water availability in Congo Basins using the storage-discharge relationship. The estimated potential drainable water storage is 481 km3 and an average residence time of 4.3 months. The methodology used is based on their previous publications. In this paper, they apply it to Congo river basins. Overall, I think this research has significant impact and advance in the quantification of water resources. I recommend a minor revision since there are a few things that I would like to get clarified.

We thank Reviewer#1 for his/her positive evaluation of our work and for highlighting the significant impact of our findings. Our responses and clarifications to all comments are below.

Major Comment:

1.Justification of using DWSA instead of TWSA in the main text: I don't fully understand why lake needs to be decoupled from TWSA as DWSA. If DWSA is used, does lake outflow need to be removed from the river discharge?

Thank you very much for that comment. This is a very good point that needs to be clarified. Actually, it was already acknowledged in item 1 of the" limitations" section, where we mention that lake water bodies are not fully disconnected from the water system and contribute to it to some extent. It is for this reason that, in addition to estimating TDWS based on the DWSA-discharge relationship, we also calculated TDWS based on the TWSA-discharge relationship. In the new version of the manuscript, we have made it clearer that the actual numbers are somewhere between these two estimates.

Additionally, in the revised manuscript, based on the comments of reviewer#2, we also consider wetlands as potential resistors in the drainage system. Therefore, we also quantify Wetland Water Storage Anomaly (WWSA) and remove it from the TWSA along with the Lake Water Storage Anomaly (LWSA). The new estimates are provided in the Tables and at various locations in the text (especially in the Section mentioned in Results - Water storage-discharge relationship). All details are provided in the Reviewer#2's bullet point #5.

But back to your valid point: it is true that lakes and wetlands are not fully decoupled from the drainage system and could contribute to the drainage system (with a longer time constant). To fully address this important point, in the revised manuscript, we now: 1) discuss the fact/limitation into the results sections, and 2) all TDWS estimates are given as a range between the two estimates.

The new text for instance is:

To quantify DWSA, we have subtracted the storage anomaly of decoupled surface water bodies, e.g., lakes (LWSA) and wetlands (WWSA), from the GRACE total water storage anomaly. In reality, these open surface water bodies are not completely decoupled from the drainage system. Lake Tanganyika for instance partially drains into the Lukuga River at Kalemie, and further feeds the Lualaba basin (32). This discharge contributes to 18% of the total annual water loss of the lake, while its water balance is mainly governed by evaporation, corresponding to 82% of its total annual water loss (28). Similarly, Lake Bangwelu and its surrounding wetlands ultimately discharge into the Luapula River, Lake Mai-Ndombe and its wetlands contribute to the Fimi River, and Lake Mweru with its surrounding wetlands are drained by the Luvua River. Given these contributions into the river system, it can be argued that the storage anomaly of these water bodies should not be fully excluded from the total water storage anomaly. To examine the effect of removing the WWSA and the LWSA from the TWSA and its impact on the results, we estimate the same *quantities by analyzing the relationship between river discharge and TWSA (Figure S5). Along with the estimates from the DWSA-discharge relationship, Table 1 lists the estimates from TWSA-discharge relationship.*

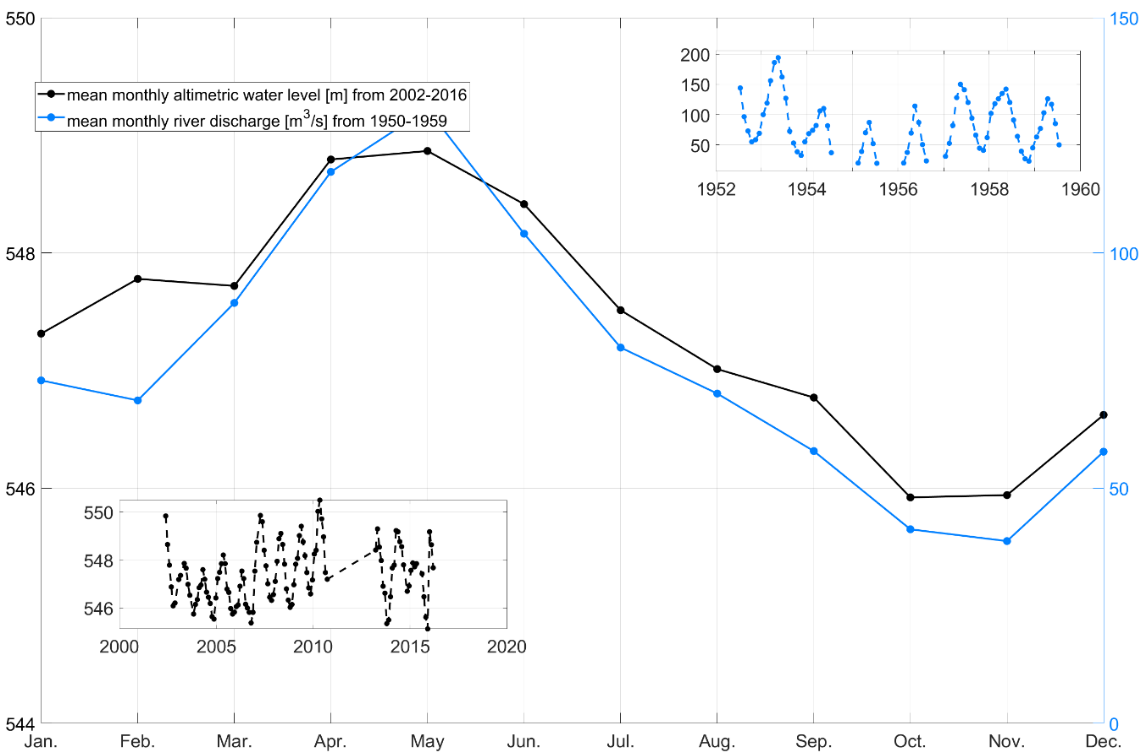
In this case, St0 and τ t differ from Sd0 and τ d for the entire Congo and for sub-basins of Lualaba-South, Lualaba-Lukuga, and Kasa ̈i, as the lakes and wetlands are distributed among these three sub-basins (see Table S2 and Figure 1). Since all storage compartments are included in TWSA, the estimate of 139 ± 6 mm for St0, which corresponds to 502 ± 22 km3, can be considered an upper bound for the estimate of TDWS. On the other hand, since the wetlands and lakes in the Congo Basin have marginal outflows and contribute to the drainage system, the assumption that they are fully decoupled from the drainage system is not perfectly true. Therefore, the estimated value of 476 ± 10 km3 for Sd0 can be considered a lower bound for TDWS. To this end, it is safer to express that the TDWS of the Congo Basin lies between 476 ± 10 km3 and 502 ± 22 km3. In Kasa ̈i, the upper bound of the TDWS is 228 ± 18 km3 for which storage of wetland and Lake Mai-Ndombe are included in the estimation. In Lualaba-South inclusion of storage from wetlands and lakes Bangwelu, Upemba, and Mweru and wetland of Mweru Wantipa results in an estimate of 107 ± 5 km3 for the upper bound of TDWS (Table 1). Over the Lualaba-Lukuga, the TDWS with and without the storage of Lake Tanganyika varies between 20 ± 1 km3 and 40 ± 1 km3. In fact, if Lake Tanganyika would have been fully involved in the river system, its storage anomaly would result in an increased TDWS by 20 ± 1 km3 for the Lualaba-Lukuga sub-basin. Our results show that about 65% of Congo's total drainable water storage is stored in the southern part of the basin in the two sub-basins of Kasa ̈i and Lualaba. The remaining 35%, is nearly evenly split between the middle Congo and the northern sub-basins Ubangui and Sangha.

In other words, the lake itself can also have a lake-storage-to-lake-outflow relationship. It might be challenging to get the outflow, but what is your comment on the lake resistance (time)? Will that be longer than 105.8 months for Lualaba-Lukuga?

This is an interesting question. This can be found out by looking at the difference between \tau^t and \tau^d. For example, for the Lualaba-Lukuga, \tau^t is 174 months and \tau^d is 105 months. The difference of 69 months is due to the time constant exerted by Lake Tanganyika. We have included this discussion in the text.

2.Uncertainties from altimetry station: The authors have a good discussion on the uncertainties on pages 13-14. How about the uncertainties from the locations of stations? From Figure1, the locations of the altimetry are not always at the outlet of the sub-basin. If the rating curve is to fit the water level from a location to the discharge of another location, how is that going to affect the results? Can the authors also list the total drainage area in Table S2?

Thank you for this valuable comment. Indeed, the uncertainty from the location of the in situ stations with respect to the virtual stations should be mentioned and discussed. This issue was thoroughly addressed in the Tourian et al. 2013 original publication of the quantile approach we use here. In that paper, the performance of the method was specifically tested using a large number of gauging stations with different distances (8-170 km) from the virtual stations. The conclusion is that as long as the water transit time between the selected VS and the gauging station is within one month, the good performance is guaranteed at the monthly time scale. Regarding the present study, the figure below shows for example a comparison between the Lukuga discharge time series and the closest altimetric water level time series which is located about 40 km away. Note again that the time series cover two different time periods. The monthly mean seasonal cycle from the time series shows that there is no time lag at the monthly time scale. Similar comparisons are obtained for the Kasai, Lualaba-North and Lualaba-South basins. Therefore, following Tourian et al., 2013, this brings confidence in the good performance of the methodology.



As already stated in the first version of the manuscript, it is also worth mentioning one more time here that the main uncertainty in the discharge estimate using our approach is most likely due to the assumption of stationarity. However, we agree that the readers need to be aware of the possible source of uncertainty due to the distance issue between the VS and the gauging station, therefore we have included it in our discussion in the section "limitations".

…Another source of uncertainty in this regard could arise from the dissimilarity between altimetric water level and legacy discharge in terms of represented dynamics. For example, if the selected virtual station is far away from the discharge gauge, resulting in a water transit time of more than one month, the good performance of the discharge estimation on the monthly time scale cannot be guaranteed. To this end, the virtual stations listed in table~\ref{tab:dischargedata} are selected in such a way that longer than one month transit time between gauge and virtual station is avoided.

Tourian, M. J., Sneeuw, N., & Bárdossy, A. (2013). A quantile function approach to discharge estimation from satellite altimetry (ENVISAT). Water Resources Research, 49(7), 4174-4186

Minor comment:

1.I think Figure S4 needs to be in the main text. Could you replace Figure 3 bottom right with Figure S4?

Thanks for this suggestion. Done.

2.Some variables are in volume, and some variables are in height in Table2. If different units must be used, could authors also list the sizes of two basins as well?

A new column is added to show the area of each basin.

3.Contribution from the groundwater: Could the different results of the sub-basin explain by the locations of the groundwater aquifers?

Well, this is a very good point. However, we are afraid that such a statement would require more proper justifications and analysis. Since we do not have access to accurate and valuable maps and data of the Congo Basin aquifers, we prefer to avoid any speculation.

4.Figure 5: instead of the minimum anomalies, could authors show the range of TWS, which is more intuitive?

We have discussed your suggestion, but we came to the conclusion that it was not fully relevant here. We believe that showing the range of TWS distracts the story from its main point. The lowest recorded mean equivalent water height anomaly represents the driest state of each grid cell, regardless of the months in which it was recorded. Therefore, we show that multiplying the driest state of each grid cell by the area of each grid cell and summing over the entire Congo Basin results in an estimate of 316 km^3, which is smaller than the estimates of TDWS (476 km^3), providing good confidence to our estimations. On the other hand, the range of TWS (max minus min) would show the variation in individual grid cells, which would not be relevant for the TDWS discussion.

Reviewer #2 (Remarks to the Author):

The manuscript attempts to address a timely assessment of water resources in an understudied region. The approach seems novel; however, the approach is not clear and lacks details. The Material and Methods section needs significant revisions. The authors should keep in mind this section should pass the reproducibility test. If adequate details cannot be included in the main text, please add them in the SI.

The authors have also failed to adequately summarize recent work in the Congo River Basin. Several publications are suggested below.

I have provided detailed comments below.

We thank Reviewer#2 for his/her very constructive assessment of our work and for pointing out our efforts to address a timely assessment of water resources in an understudied region. All comments are important and relevant and we have responded to them in detail.

In addition, I would also like the authors clarify the following. The estimation of drainable water storage is estimated based on GRACE, historical flow records and altimetry data. The GRACE storage anomalies include canopy and soil storage, lakes, wetlands and groundwater. The altimetry data is available only for large rivers. The analyses use only lake storage to estimate drainable water storage. Given that nearly 50% of the river basin area is under tropical rainforest and the presence of wetlands that exert significant control on drainage, can the authors justify the use of lake only to estimate drainable water? Can they show or justify that ignoring other storage anomalies will not alter the drainable water estimates?

Thank you for this critical look on our approach and these legitimate questions. Indeed, we fully agree with your remark regarding the contingent resistance in the drainage system from wetlands. In fact, wetlands, similarly to lakes in the Congo River basin represent a resistance in the drainage system and are not completely decoupled from it. This was acknowledged in the "Limitations" section, where the estimates based on the Total Water Storage Anomaly (TWSA, i.e. without any decoupling) are given as upper limits.

However, after reading your concerns on that matter, we have decided to also quantify Wetland Water Storage Anomaly (WWSA) and remove it from the TWSA along with the Lake Water Storage Anomaly (LWSA). This is now included in the new version of the manuscript, with the new estimates provided in the Tables and at various locations in the text (especially in the Section mentioned in Results - Water storage-discharge relationship). All details are provided in the Reviewer's bullet point #5.

On the other hand, we would add that the other storage compartments that Reviewer#2 mentions like soil, canopy or groundwater storages are per definition fully coupled to the drainage system. So they should not be excluded from TWSA.

1. Overall, the figure captions do not adequately explain what is presented in the figure and are ambiguous.

The period of analysis and spatial and temporal resolutions are not mentioned in the text (Data and Methods or in SI). This is another key weakness in the manuscript.

We carefully revised all figure captions and made sure they adequately describe what is represented in the Figure.

2. The reference numbers appear out of order; #44 appears first, whereas #1 appears in page 15.

This is due to the bibliography style, which sorts the bib entries alphabetically. We changed the style so that the references are sorted by their appearance.

3. Paragraph 1: Authors have not acknowledged several contributions on climate and water resources. I have highlighted several below. None of the IPCC reports, which have highlighted the current state of science and research needs, have been cited.

a. Simulated hydrologic response to projected changes in precipitation and temperature in the Congo River basin - (1).

b. Data-driven estimates of evapotranspiration and its controls in the Congo Basin - (2).

c. Evaluation of historical and future simulations of precipitation and temperature in central Africa from CMIP5 climate models - (3).

d. Contrasting controls on Congo Basin evaporation at the two rainfall peaks - (4).

e. The Relationship of Rainfall Variability in Western Equatorial Africa to the Tropical Oceans and Atmospheric Circulation. Part I: The Boreal Spring - (5).

f. The Relationship of Rainfall Variability in Western Equatorial Africa to the Tropical Oceans and Atmospheric Circulation. Part II: The Boreal Autumn - (6).

g. Rainfall and temperature variations over Congo-Brazzaville between 1950 and 1998 - (7).

h. Balancing hydropower and biodiversity in the Amazon, Congo, and Mekong - (8).

i. Fragmentation and Flow Regulation of the World's Large River Systems - (9).

j. Water Issues in the Democratic Republic of the Congo: Challenges and Opportunities (10).

Thank you for providing such a detailed list of relevant studies. We now cite these contributions throughout the text (not necessarily in the first paragraph).

4. Main objectives (paragraph 3): objective 2 is not clear – resistance to what? Objective 3 is too vague. There are several studies, since the 1960s, that have quantified available and accessible water resources. What are the new insights – please be specific.

We revised the text to make it more clear.

"Within this complex context, the present study targets two main objectives: 1) to quantify, for the first time, the contemporary TDWS over the entire Congo Basin and the geographical distribution of water availability among its major sub-basins Kasa¨ ı, Middle- Congo, Ubangui, Sangha and Lualaba (Figure 1 and Table S1), 2) estimate the hydraulic time constant representing the resistance of a basin to discharge its water storage for the Congo Basin and its sub-basins. We further assess the plausibility of our results with respect to other external estimates and show that our estimates are consistent with previous investigations done over the Amazon basin. Finally, we discuss the implications of our findings regarding Congo's water resource availability."

5. (Section mentioned in Results - Water storage-discharge relationship)

The control lakes and wetlands exert on water storage and flow regulation has been well documented (e.g., see Alsdorf et al., (11) http://dx.doi.org/10.1002/2016RG000517, and Aloysius and Saiers (1) https://doi.org/10.5194/hess-21-4115-2017). Authors have recognized this in the discussion section. These controls are prominent in the Lualaba-South and Kasai. I also want to emphasize that Kasai sub-basin does not have larger lakes as the Lualaba-South or the Lualaba-Lukuga. Thus, the generalization that lakes exert control over flows and storage is a weak argument. Alsdorf et al., citing several studies, highlight the wetlands' control on storage and flows can be significant as lakes.

As mentioned earlier, we find this remark very useful and we agree that wetlands, such as lakes, also exert control on water storage and flow regulation, as previously documented. Therefore, similarly to lakes, we have included the wetland contributions in our analysis (Figure 1 and Figure S4; see the new section in Data for the detailed description on the sources and calculations).

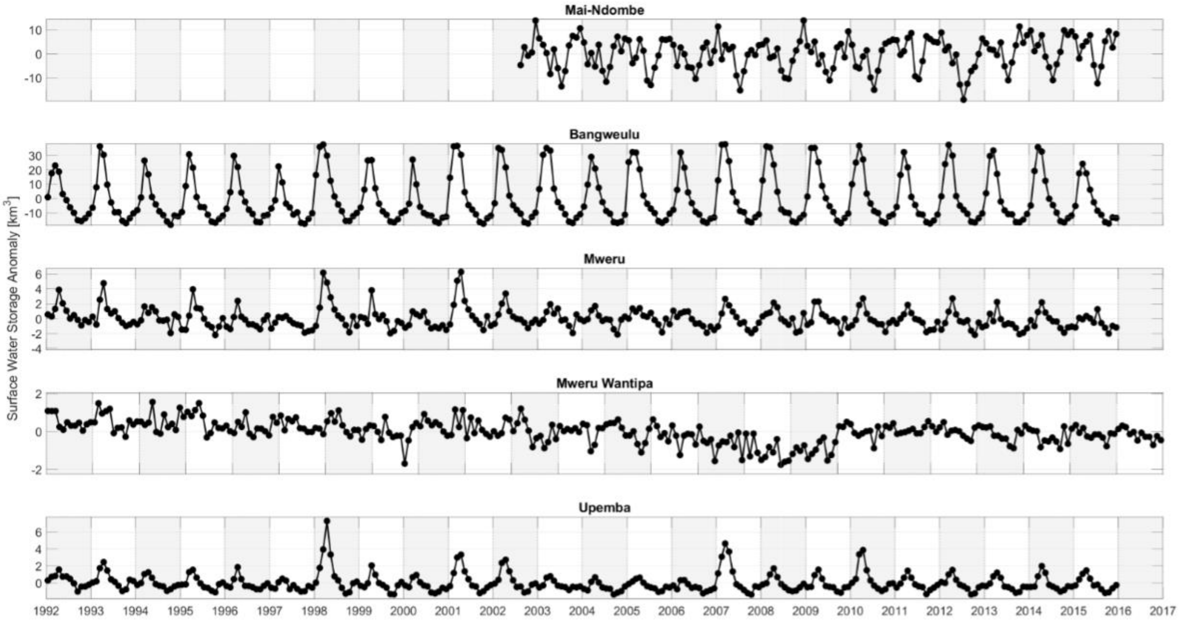


Figure S2: Time series for the period 1992–2015 of Surface Water Storage Anomaly (SWSA) of five wetlands of Mai-Ndombe, Bangwelu, Mweru, Mweru Wantipa and Upemba derived from the combination of Surface Water Extent (SWE) estimates from the Global Inundation Extent from Multi-Satellite (GIEMS-2) with topographic data from the Forest And Buildings removed Copernicus 30m Digital Elevation Model (FABDEM) following an hypsometric approach

As you indicated, assuming that wetlands are fully decoupled from the drainage system, the impact of wetlands could indeed be significant, as shown by the following results. The first table shows our previous results where we obtained DWSA by subtracting LWSA only. The second table shows our new results where both LWSA and WWSA (Wetland Water Storage Anomaly) are subtracted from TWSA. The results differ in the two sub-basins of Kasai and Lualaba-South that have wetlands. The inclusion of wetlands in the Lualaba-South sub-basin has a significant impact, as the estimated TDWS decreases from 104 to 67 km³.

Table S4: Estimated parameters to derive storage-driven discharge from water storage anomaly over Congo and its sub-basins. DWSA = TWSA - LWS

	Total Water Storage Anomaly (TWSA)			Drainable Water Storage Anomaly (DWSA)		
Basin	τ^t [month]	S_0^t [mm]	$S_0^t\times$Area [km^3]	τ^d [month]	S_0^d [mm]	$S_0^d\times$Area [km^3]
Kasaï	10.1±0.8	255±20	228±18	**10±0.8**	**254±18**	**227±17**
Middle Congo	2.6±0.2	103±7	90±6	2.6±0.2	103±7	90±6
Ubangui	8.6±0.8	97±8	63±5	8.6±0.8	97±8	63±5
Sangha	5.7±0.5	95±9	20±2	5.7±0.5	95±9	20±2
Lualaba-North	1.7±.3	89±11	22±3	1.7±0.3	89±11	22±3
Lualaba-South	13.9±0.9	235±12	107±5	**13.7±0.7**	**233±12**	**104±6**
Lualaba-Lukuga	174.2±4.7	148±3	40±1	**105.8±3**	**88±4**	**20±1**
Weighted average			$\sum$ 571 ± 20			$\sum$ **548 ± 19**
Congo	4.4±0.2	139±6	502±22	**4.3±0.2**	**135± 7**	**481±24**

Table S5: Estimated parameters to derive storage-driven discharge from water storage anomaly over Congo and its sub-basins. DWSA = TWSA - LWSA - WWSA

	Total Water Storage Anomaly (TWSA)			Drainable Water Storage Anomaly (DWSA)		
Basin	τ^t [month]	S_0^t [mm]	$S_0^t\times$Area [km^3]	τ^d [month]	S_0^d [mm]	$S_0^d\times$Area [km^3]
Kasaï	10.1±0.8	255±20	228±18	**9.3±0.2**	**250±5**	**220±4**
Middle Congo	2.6±0.2	103±7	90±6	2.6±0.2	103±7	90±6
Ubangui	8.6±0.8	97±8	63±5	8.6±0.8	97±8	63±5
Sangha	5.7±0.5	95±9	20±2	5.7±0.5	95±9	20±2
Lualaba-North	1.7±.3	89±11	22±3	1.7±0.3	89±11	22±3
Lualaba-South	13.9±0.9	235±12	107±5	**7.7±0.2**	**149±4**	**67±2**
Lualaba-Lukuga	174.2±4.7	148±3	40±1	**105.8±3**	**88±4**	**20±1**
Weighted average			$\sum$ 571 ± 20			$\sum$ 503 **± 10**
Congo	4.4±0.2	139±6	502±22	**4.3±0.1**	**133± 3**	**476±10**

Note that Lake Tanganyika is an outlier, and in most cases the outflow is nearly equal to the inflows. Authors should recognize these and update relevant sections including Methods and Materials.

According to Bergonzini, L. (2002) (Figure 12), the lake output, which is the sum of E and Qo, is relatively constant throughout the year, with an average value of 172 mm/month. This underlines the crucial role of inflow (P+inflow), which is responsible for the intra-annual variations of water storage in the lake. Moreover, Bergonzini, L. (2002) shows that in terms of losses, evaporation from the lake surface, which accounts for about 82% of the total annual loss, is the most important term compared to discharge via the Lukuga River, which accounts for only about 18% of the total water loss.

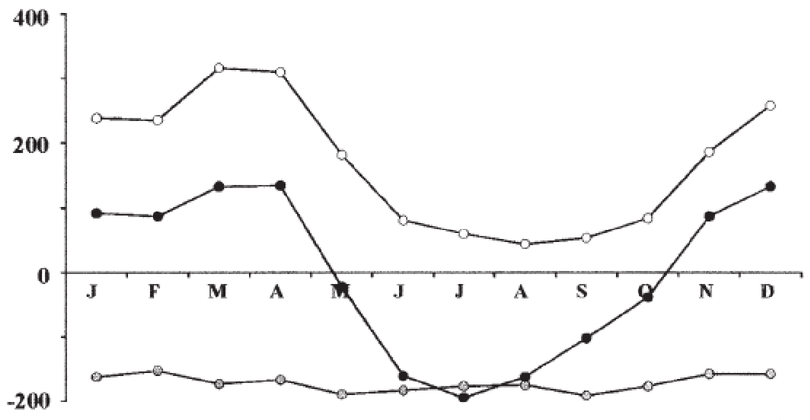


Figure 12. Mean monthly profiles of observed water storage (ΔSo; black circles), total input (P+Qi; open circles) and total output (-E-Qo; grey circles) of the reconstructed mean monthly water balance, expressed in mm over the lake surface (32 600 km^2).

In the revised manuscript, we have acknowledged the findings of Bergonzini, L. (2002) in our text and it helped refine our analysis.

Bergonzini, L. (2002). Computed mean monthly water balance of a large lake: the case of Lake Tanganyika. In Lake Issyk-Kul: Its Natural Environment (pp. 217-244). Springer, Dordrecht.

Overall, I think the following questions should be answered or clarified. Would the results be different if wetland storages are included in the analysis (a) as a separate storage entity or (b) included as part of the lake if there is connectivity?

We addressed all of these questions accordingly. See below.

It appears that authors have only considered larger lakes that have reported values for

... Overall, the ratio of LWSA to TWSA for the Congo Basin is about 10% (Figure 2 bottom), but with regional differences, from 5% in Kasai, 15% in Lualaba-South to 60% in Lualaba-Lukuga... → As I mentioned elsewhere, the Lualaba-Lukuga is an outlier. Published work and water balance studies reveal that Lake Tanganyika alone exert significant control over outflows (see (12, 13) and other references). Authors should recognize and acknowledge these facts. Generalizing results based on high LWSA/TWSA ratios may lead to biased overall conclusions.

Thanks for raising this point. In the revised manuscript, we addressed your point and provided a detailed description of storage anomalies:

Figure 2 shows time series of TWSA, WWSA and LWSA for seven sub-basins and the entire Congo Basin in form of equivalent water height in millimeter, which are obtained by dividing storages by the area of corresponding basin. The time series represent distinct seasonal variations, with peak values reached in October and November in the northern sub-basins (Ubangui, Sangha) and in Middle-Congo that straddles on both northern and southern part of the basin. The time series display peak values between February and April in the southern sub-

basins (Kasa ̈i, Lualaba-North, Lualaba-South and Lualaba-Lukuga). The TWSA time series across the entire Congo typically shows a double annual peak, one originating from the contribution of the southern basins and one from the northern ones (Figure 2). Over the entire Congo, LWSA account for approximately 10% of the TWSA amplitude (100 mm), with most of its

variations (about 80%) coming from Lake Tanganyika. The WWSA, which accounts for about 20% of TWSA, exhibits significant seasonal variations linked to the variations in the southern parts of the basin, which is to be expected since the wetlands are primarily located in Kasa ̈i and Lualaba-South sub-basins.

The Kasa ̈i WWSA, with an amplitude of about 10 mm, represents the equivalent water height of about 10 km3 wetland water storage, located in the surroundings of the Lake Mai-Ndombe (Figure S2), which is part of the Tumba-Ngiri-Maindombe, one of the world's largest wetlands, and a site of major significance as recognized by the Ramsar Convention (https://rsis.ramsar.org/ris/1784). LWSA in the Kasa ̈i is dominated by Lake Mai-Ndombe itself, which fluctuates with an amplitude of about 3 km3 (Figure S1), corresponding to an LWSA with an amplitude of about 3 mm. Over the Lualaba-Lukuga, LWSA, that accounts for about 50% of the TWSA, comes from Lake Kivu with a storage variation of about 2 km3 and Lake Tanganyika with a variation of about 20 km3 (Figure S1), imposing thus considerable control on the discharge of the Lukuga River (28, 29). Over the Lualaba-South, Bangwelu Wetland with about 20 km3, Mweru Wetland with 4 km3, Mweu Wantipa Wetland with about 1 km3 and Upemba Wetland with about 2 km3 of amplitude (Figure S2) are the main contributors of WWSA with 100 mm amplitude, while lakes generate LWSA with an amplitude of about 10 mm.

Authors use LWSA to estimate DWSA and ignore the contribution of wetlands. The GRACE estimates also include soil water and canopy storage. Given that nearly 50% of land cover is dense tropical rainforest and water bodies occupy ~3% of the catchment, can authors confirm that the influence of water stored in (i) forest canopy, (ii) soils and (iii) wetlands are negligible? These are major weaknesses in this study. Authors should clearly establish that ignoring the wetlands will not change the results and conclusions. Authors acknowledge the importance of wetlands elsewhere when they describe "basin resistance", however, they ignore the importance in the analysis.

Please see our response to your earlier comment on this matter.

Many interpretations in paragraph 1 in page 7 are not supported by the analysis. If they indeed are, please clarify. For example, I am finding it difficult understand how the statement "…the drainage of Middle Congo, Lualaba-South and Lualaba-Lukuga appears to occur with a faster rate…" is supported by the analysis presented here. There several instances like this.

AGAIN, without considering the influence of wetlands, and solely based on estimates of lake storage anomalies, this estimate is not closer to the true values.

This paragraph basically contains our observations from Figure 3 showing the discharge-DWSA relationship. In the revised manuscript, we rephrase this paragraph by better referencing figures.

For context, could the authors provide how the estimate (481 ± 24 km3) compare with runoff/rainfall ration (~0.4) for the Congo. By the way, are these annual values?

The numbers are absolute and in essence can be interpreted as a long-term average value. The TDWS estimate is predominantly dictated by the slope in discharge-DWSA relationship. From runoff/rainfall ratio, one cannot directly make a direct connection to the TDWS value.

The comments below are related to sections in the Materials and Methods, which the authors have mentioned in the Results section.

a. Total Water Storage Anomaly from GRACE: The description is too abstract. Please expand and clarify – C20, C30, degree 1, destriping filter, why the corrections are needed for tidal aliasing error, what is GIA and why this adjustment is needed?

We provided the reasons for all these corrections and refinements of GRACE data.

Given that the GRACE estimates of the lowest degree zonal harmonic coefficient are not accurate, we replace the GRACE coefficients C 2,0 and C 3,0 with the coefficients obtained from the Satellite Laser Ranging (SLR) data.. Furthermore, since GRACE does not provide an estimate for degree 1, we add the coefficients for degree 1 according to the estimate of (33). Due to imperfect tidal models, the GRACE solutions are contaminated by a primary and a secondary tidal error, resulting in errors in the estimated TWSA over the Congo of up to one 8 mm (see Figure 4.40 in (37)).

Therefore, we eliminated the primary and secondary tidal alias errors of the main tidal components S1, S2, P1, K1, K2, M2, O2, O1, and Q1 from the monthly GRACE solutions using a least-squares Fourier analysis (37). When glacial isostatic adjustment (GIA) is considered as predicted by the ICE6G-D model (?), a contemporary geoid rate of about –0.1 mm/year is expected over the Congo. Therefore, to avoid the GIA-driven trend in the TWSA time series, we corrected GIA using the model by (1). The coefficients are then filtered using a Gaussian filter with radius 350 km and the destriping filter proposed by (34). Finally, the basin-wise leakage error is mitigated by the so-called data-driven method developed by (43).

Most of all, why are the authors not using the published GRACE products? It's not clear if the data are derived by the authors or they are using published data products (NASA, JPL). The spatial and temporal resolutions, period of analyses are not provided.

We strongly believe that all these refinements lead to a more reliable GRACE data than those published products.

b. Lake water storage anomaly: this section fails the reproducibility test. With the information given, it will be extremely difficult even for an expert to reproduce the results.

We have reworked and rewritten this section. All information are now provided so that the results are reproducible.

c. River discharge: The rating curves are based on 1950-59 stream flow data (estimated based on water depth, if you look at the original data report) and present day (which years and temporal resolution ???) altimetry data. Briefly explain how flow rates are estimated or include the brief in SI. Please also confirm that the precipitation patterns during the present-day and 1950-59 periods are not significantly different.

Include all the relevant citations.

The time frames are explicitly mentioned in Table S2:

Table S2: Discharge data source for the Congo Basin and its sub-basins. Water level from satellite altimetry is used to update discharge for the basins highlighted in gray using the quantile function approach [1]. J2, J3, Env and SRL in the table refers to Jason-2, Jason-3, Envisat and Saral/AltiKa missions, respectively.

Basin	in situ discharge				water level from altimetry			
	station	Lat [°]	Lon [°]	time period	Mission	Lat [°]	Lon [°]	time period
Kasaï	Kutu-Moke	−3.18	17.38	1932–1991	J2&J3	−3.06	16.62	2009–2020
Middle Congo*	Brazzaville	−4.27	15.32	1990–2020				
Ubangui	Ubangui	4.37	18.61	1990–2020				
Sangha	Quesso	1.62	16.05	1990–2020				
Lualaba-North*	Ponthierville	−0.35	25.45	1932–1959	J2&J3	0.72	24.56	2009–2016
Lualaba-South	Kindu	−2.95	25.92	1933–1989	Env&SRL	−2.96	25.93	2002–2016
Lualaba-Lukuga	Lukuga	−5.91	29.19	1950–1959	Env&SRL	−5.74	26.91	2002–2016
Congo	Brazzaville	−4.27	15.32	1990–2020				

*: incremental basin

We improved this section to make the methodology much clearer.

We estimated discharge Q based on water level from satellite altimetry H using the quantile mapping approach proposed by Tourian et al. (2013). There, we obtain the so-called rating curve function Q = F (H) by turning both data into their quantile functions. The quantile functions of discharge and altimetric water level have a same x-axis, which is the cumulative probability. Therefore, by connecting their y-axis directly we can obtain F (.) (See Figure 6 in Tourian et al. (2013)). Since this approach does not explicitly include the time coordinate, the requirement for synchronous datasets becomes obsolete. This means that pre-satellite river discharge data sets can be salvaged and converted into usable data for the satellite altimetry time frame.

The challenges of stationarity assumption are fully addressed in the "limitation" section in item number 1:

Due to the poor data availability, we estimated river discharge time series of Kasa ̈i, Lualaba-North, Lualaba-South and Lualaba-Lukuga (Table S2) by developing rating curves between satellite altimetry data after 2002 and legacy discharge data before 1991. Again, here, we made an assumption of stationarity in the long term behaviour of discharge for these sub-basins. However, any deviation from stationarity would lead to uncertainty in the estimated discharge from altimetric data. Nevertheless, we argue that, in terms of the overall dynamics and magnitude, our discharge estimates (Figure S2) are consistent with precipitation (Figure 4) and water storage anomalies (Figure 4). Another source of uncertainty in this regard could arise from the dissimilarity between altimetric water level and legacy discharge in terms of represented dynamics. For example, if the selected virtual station is far away from the discharge gauge, resulting in a water transit time of more than one month, the good performance of the discharge estimation on the monthly time scale cannot be guaranteed. To this end, the virtual stations listed in table S2 are selected in such a way that longer than one month transit time between gauge and virtual station is avoided.

Tourian, M. J., Sneeuw, N., & Bárdossy, A. (2013). A quantile function approach to discharge estimation from satellite altimetry (ENVISAT). Water Resources Research, 49(7), 4174-4186

d. Methodology: Briefly explain the methods used to calculate water storage anomaly and discharge; elaborate further "… Due to its complexity and very different characteristics…";

This section does not provide any information about how the fluxes are calculated other than citing references (31, 36 and 30). This should be expanded and explained further in details in the SI.

Same comment for "Estimation of Total Drainable Water Storage and basin resistance" section as well.

The section on methodology has now been improved with details on the methods. We realized that mentioning a part of the methodology in the manuscript and a part in the SI makes the methodology less understandable. Therefore, in the revised manuscript, the entire methodology is described in the manuscript itself, which is supported with relevant details to make it reproducible.

e. SI – S1: Methods section and Table S1 does not state how the data are acquired. Are they based on observed values? If yes, are they for the analyses period 2002-2018?

Precipitation estimates are from GPCC data and evapotranspiration from ERA5 for the period 2002-2018. Discharge values were obtained from discharge data within the period specified in Table S. We have included this info in the caption of the table.

Either in "Methods" section or under SI – S1, authors should provide the methods used to estimate water storage anomaly and discharge; merely stating they followed (31, 36, 30) is not adequate.

See our response above. The section on methodology has now been improved with details on the methods.

f. SI – S3: briefly explain how the sources of data used to estimate lake volumes and storage anomalies. As it is, the details are not sufficient to reproduce the results presented in the analysis. Did the authors use all the lakes in the sub-basins identified in Figure 1? If selected lakes are used, then include the details in a table in SI.

The selected lakes and their corresponding data sources were listed in Table S3. And yes, they are all shown in Figure 1. In the revised manuscript, we have improved the section on lake water storage anomaly.

g. SI – S5: the period of analysis is 2002-2018. Please clarify as to why the precipitation plots are for 1891-2019. How are these data and at what spatial/temporal-scale used in the analysis?

Figure S5, in the revised manuscript S7, is to support the discussion provided in the section of "Water storage-discharge relationship". In that discussion, we mainly rely on the spatiotemporal precipitation pattern. Such a long time period is selected to obtain the most reliable climatology.

…Such a pattern is also seen in sub-basins Ubangui, Sangha, Kasa¨ ı and Lualaba-North. In comparison to these sub-basins, within the draining phase Middle Congo and Lualaba-South appears to drain with a faster rate since the discharge-storage relationship represents a rather linear. ***The unique behavior in these sub-basins may be explained by the fact that the soils are particularly shallow and sandy (31) and drain quickly as precipitation decreases (Figure S7****). The (sub-)sub-basins of Lualaba show different relationships. The presence of lakes and wetlands, with massive storage capacities like the Bangwelu swamp, the Upemba depression and Lake Tanganyika, greatly influences the flow regime of the downstream sub-basins (52). In the Lualaba-North, the discharge reaches its maximum in November, while in the Lualaba-South and Lualaba-Lukuga the maximum discharge is reached in April–May (25).* ***This is mainly driven by the difference in precipitation patterns over these three sub-basins (figures S7 and 4)****.*

6. Congo versus Amazon (page 11): The comparison here makes sense and is plausible. However, the analyses, interpretation and discussion do not convince nor conclusively support the facts presented here.

Thank you for this comment. We rephrased the text to make our point more convincing. Our main idea is, in the absence of ground truth data, to provide comparisons to reinforce the plausibility of our estimates. Since the Amazon is the only other basin with TDWS estimate and to a great extent very similar to Congo in terms of climate, vegetation etc., we believe this comparison supports our discussion.

The only other basin, for which a TDWS estimate is available is the Amazon Basin (25). Since Congo and Amazon are both catchments dominated to a great extent by similar tropical cli mate (33), rain forest vegetation pattern and geomorphology, we provide here a mutual assessment of the results. Comparing the estimates over these two basins, we obtain a ratio of about 25% between Congo's TDWS 476 ± 10 km3 to Amazon's TDWS 1766 ± 47 km3 (Table 2). This is roughly equivalent to the ratio estimated between their mean annual discharge to the ocean (Congo 40 000 m3/s, Amazon 209 000 m3/s), and also the ratio between the amplitude of their water storage anomaly (Congo 40 mm, Amazon 170 mm) as well as the ratio between their recharge (P – ET) (Congo 300 mm/yr, Amazon 1100 mm/yr) (34). In addition, the hydraulic time constant of 4.3 ± 0.2 months for the Congo basin (Table 1) is similar to the Amazon basin 4.4±0.12 months (25). In the absence of ground truth *data to directly validate our results, these comparisons reinforce the plausibility of our estimates.*

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2. M. W. Burnett, G. R. Quetin, A. G. Konings, Data-driven estimates of evapotranspiration and its controls in the Congo Basin. Hydrology and Earth System Sciences 24, 4189–4211 (2020).

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5. S. E. Nicholson, A. K. Dezfuli, The Relationship of Rainfall Variability in Western Equatorial Africa to the Tropical Oceans and Atmospheric Circulation. Part I: The Boreal Spring. Journal of Climate 26, 45-65 (2013).

6. A. K. Dezfuli, S. E. Nicholson, The Relationship of Rainfall Variability in Western Equatorial Africa to the Tropical Oceans and Atmospheric Circulation. Part II: The Boreal Autumn. Journal of Climate 26, 66-84 (2013).

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12. L. Bergonzini, in The Issyk-Kul Lake: Evaluation of the Environmental State and Its Remediation, J. Klerkx, B. Imanackunov, Eds. (Kluwer Academic Publishers, 2000).

13. S. E. Nicholson, Historical and modern fluctuations of Lakes Tanganyika and Rukwa and their relationship to rainfall variability. Climatic Change 41, 53-71 (1999).

The authors of the manuscript entitled "Current availability and distribution of Congo basin's freshwater resources", tried to estimate drainable water storage (TDWS) of the Congo basin, indicating that it currently holds ~ 480 km3 of water unevenly distributed throughout the basin. The authors also estimated the time constant for draining its entire water storage to be ~ 4.3 months. Some insight into Congo' water resource availability is provided.

Overall, the authors characterized water storage changes and the relationship between river discharge and TDWS over the Congo basin. A lot of numbers on this characterization have been presented. The authors compared these numbers with FAO-based renewable groundwater storage changes and those for the Amazon given by other studies.

We would like to thank Reviewer#3 for his/her assessment of our study.

Unfortunately, this characterization does not seem to provide process-based understanding of changes in the hydrology and its ecological, environmental, and/or climatic consequences/feedback for the vast region of the African continent.

Also, the methods used by the authors are quite standard, mostly reliant on GRACE observations and some publicly available altimetry/optical image-based data sets that are built on the work conducted previously.

We believe that there is a misunderstanding here. The method used is not a standard method as mentioned by Reviewer# 2. A similar method was first published in 2018 (Tourian et al., 2018), which was tested over the Amazon Basin. This study is the first to modify the original method to make it applicable to basins with much more complicated behavior than the Amazon Basin.

I feel that this study might not reach the standard of publication in Communications Earth & Environment, though Communications Earth & Environment does not have such a high standard of Nature Communications, which I clearly note. This study might be more suited to a specialized journal outlet.

We thank the Reviewer for this statement but we strongly disagree with this opinion.

We believe that our original study addresses key questions regarding freshwater availability and distribution of the Congo

Basin, a highly vulnerable region that plays a key role in the global biodiversity, water and carbon cycles, and that remains understudied. Here we provide unique and crucial estimates that are strongly needed to further understand this complex system. Thus, we believe our results and manuscript are of great interest for the broad audience of Communications Earth and Environment and will generate a high level of interest in its diverse readership. Given the interdisciplinary scope of our work and the broad implications of our findings, our results will be of significant relevance to hydrology, ecology, meteorology, water resources, remote sensing, and environmental management communities.

Regarding the presentation, overall, it is good. But I note that the authors use a couple of paragraphs detailing the limitations of this study in the discussion section. This reads like the narratives that mostly occur in a specialized journal.

We thank Reviewer#3 for pointing out the good quality of the presentation. Regarding the detailed paragraphs about the limitations of the study, we believe it is an important part of the analysis and the discussion of our paper. It indeed provides the readers with some confidence in our results, while it shows that we took well in consideration all sources of uncertainties. We don't believe that this good practice of science is reserved to specialized journals. We are sure that this is useful and needed for a journal such as Communications Earth & Environment.

Figures 1-2 are not quite informative. Figure 1 presents basic information on the geography of the Congo basin. Figure 2 shows total water storage changes from GRACE and GRACE Follow-On, and lake water storage changes from satellite altimetry over the Congo basin and its subbasins. I believe that these figures should be put in the Supporting Information.

We believe that Figures 1 and 2 are quite informative for understanding basin hydrology. In the revised manuscript, Figure 2 also includes time series of wetland water storage anomalies (WWSA) for two sub-basins and the entire Congo. Together with the lake water storage anomaly, they clearly show their contributions to the total water storage anomaly and their temporal behavior, which is very important for the interpretation and the analysis made in this study.

15th Feb 23

Dear Dr Tourian,

Please allow us to sincerely apologise for the long delay in sending a decision on your manuscript titled "Current availability and distribution of Congo Basin’s freshwater resources". It has now been seen by 2 reviewers, the original Reviewer #1 and a new Reviewer #4, whose comments are appended below. Unfortunately Reviewers #2 and #3 did not submit further reports. In the light of the advice we have received I regret to inform you that we cannot publish your manuscript in Communications Earth & Environment.

You will see that Reviewer #4 raises substantive concerns. Taking these points together with our editorial considerations, we remain unable to conclude that the methodological approach is sufficiently explained and justified to support the conclusions and enable the work to be reproducible. Unfortunately, these reservations are sufficiently important to preclude publication of this study in Communications Earth & Environment.

I am sorry that we cannot be more positive on this occasion and thank you for the opportunity to consider your work.

Best regards,

Rahim Barzegar, PhD
Editorial Board Member
Communications Earth & Environment
orcid.org/0000-0002-1941-2991

Joe Aslin
Senior Editor
Communications Earth & Environment

Reviewers' comments:

Reviewer #1 (Remarks to the Author):

The authors have answered or considered most of my previous comments. I only have two minor comments:
1. Could you please provide the size of the wetlands for each sub-basin?

2. What are the used approaches to quantify the water resources in Congo Basins? I think it’s worth to mention some estimates in introduction (to introduce the watersheds) similar as you compared with FAO in page 14.

Reviewer #4 (Remarks to the Author):

Review for the manuscript entitled “Current availability and distribution of Congo Basin’s freshwater resources” by Tourian, et. al.,

I was invited late to review this article. To provide an unbiased opinion, I carefully read the paper, and additional comments are still captured, and a thorough revision is required before the final recommendation.

Generally, the version I received does not have line numbers. Thus, in some instances, I quoted what I wanted to comment on. It is very hectic to provide comments on a version of a manuscript not lined-numbered.

I have a major comment on what is referred to as a Drainable Water Storage Anomaly (DWSA), which was obtained by subtracting the LWSA and WWSA from the GRACE.

In general, GRACE Total Water Storage Anomaly (TWSA) is an integrated anomaly of all the changes in terrestrial water storage column in all forms including surface water storage, groundwater storage, and soil moisture storage. The two components utilized in this research (i.e., LWSA and WWSA) are part of the surface water storage, and to some extent soil moisture. Subtracting these two components will not lead to the DWSA. I cannot understand this?!!! At best these estimates would be a proxy of the groundwater storage. Please clarify more about that in the methodology section. More evidence is needed, and a clear reproducible methodology is required.

Another major flaw is the spatial and temporal differences between GRACE and the other two estimates, more details are needed in the methodology section about the combination of these three ancillary products.

Additional major comments are provided as follows,

Major comments,

Abstract,

The claim that the Congo River Basin's “freshwater availability remains highly unknown” is bold and unsupported.

Introduction,

The claim that the Congo basin is “Surprisingly, the Congo Basin has not
attracted as much attention among the scientific communities as done for other large tropical river basins (4) and remains relatively understudied, currently leaving an insufficient knowledge of its hydrology characteristics (8)” this is also very surprising. A naïve search on the web of science or google scholar will prove the opposite in terms of the Congo basin hydrology.

Before introducing GRACE, you could introduce other remote-sensing hydrological sensors, or just make the reader ready for this transition from the lack of in-situ data to the abundance of hydrological satellite-based sensors.

Result,

The authors claimed that “since the wetlands in the Cuvette Centrale are fully connected to the river system (27), their storage should not be removed from the TWSA to obtain DWSA”. Therefore, TWSA of these three basins can be equally considered as DWSA.” As I introduced first, it is well-known that GARCE is a sum of various components since there are no wetland/river systems, GRACE anomaly cannot be only considered as DWSA. This claim is incorrect. I would consider them as related to groundwater storage anomaly, for instance.

Fig.2 units are missing.

Fig. 3 what do these arrows refer to?

Fig. 4 I am very confused about the fig caption. What is “left” and what is “right" in the fig. caption? I thought the Fig is showing the correspondence between Q and DWSA that is only good at four basins. The rest is very inconsistent. Where is the GPCC came from? Also, can you add a legend for the two lines? And please use different line symbols, not only color.

Methodology

Temporal length of GRACE observation not provided.

The utility of the ITSG-2018 is not verified? Or at least compared against other products. It is well-known that different GRACE products will have different estimates. And, in terms of providing drainable water storage in a basin, every single GRACE product will introduce a different figure.

Another very obvious limitation is the Lake water volume, the hydroweb website provides the Lake water height as a single water height estimate for some selected Lakes across a basin. To convert the estimates to Lake volume water integrated lake area should be introduced, which I suspected that areal estimation came from the HydroSat source. More clarification is needed for reproducibility.

Also, converting the Lake water height/volume??? to the anomaly is not clear. How did you do this? And how is this compared to the TWSA from GRACE?

The SWE component is a grided 0.25 x 0.25 and the native spatial resolution of GRACE is 3 x 3 degrees, how both are combined in the drainable water estimation? Also, at a temporal scale, GRACE and SWE should have produced relative to the same baseline anomaly. How did you do that? Similar limitations apply to the rest of the datasets.

For the estimation of Total Drainable Water Storage and basin resistance, in this section the authors claimed to use the monthly mean value from GRACE and Q, are the data available in the sub-monthly format, especially GRACE???

Minor comments

Gt. Abbreviation not pronounced at first.

Dear Editor and Reviewers,

Please find enclosed our point-by-point response to the reviewers' comments on the manuscript entitled "Current availability and distribution of Congo basin's freshwater resources" that we submitted as a contribution to *Communications Earth & Environment*.

With respect to the detailed responses, the reviewers' assessments appear below in black and we highlighted our answers in blue. We believe we have addressed each comment carefully and hope that the responses meet your expectations.

Best Regards,

Mohammad J. Tourian, on behalf of all authors

Reviewers' comments:

Reviewer #1 (Remarks to the Author):

The authors have answered or considered most of my previous comments. I only have two minor comments:

1. Could you please provide the size of the wetlands for each sub-basin?

Yes, we agree with the reviewer that this is information that should be provided. This is now added in the manuscript.

For each wetland, we then isolate the SWS variations and remove the long-term mean to obtain the Surface Water Storage Anomaly (SWSA). Figure S2 shows SWSA time series over the selected wetlands Mai-Ndombe (18550 km2), Bangwelu (30150 km2), Mweru (10820 km2), Mweru Wantipa (4640 km2) and Upemba (12370 km2) for the period 1992—2015 in km3. With the exception of the Mai-Ndombe wetland, which is located in the Kasaï sub-basin, the others are in Lualaba-South, covering a total area of 57980 km2.

2. What are the used approaches to quantify the water resources in Congo Basins? I think it's worth to mention some estimates in introduction (to introduce the watersheds) similar as you compared with FAO in page 14.

We have added the following sentences in the introduction section:

…but also acts as a carbon sink that stores about 80 Gigaton of carbon (equivalent to about 2.5 years of current global anthropogenic emissions) (7). Despite its importance, knowledge about the availability and distribution of water resources in the region is still inadequate. To the best of our knowledge, the only source for water resource estimates in the Congo Basin is Food and Agriculture Organization's AQUASTAT (FAO-AQUASTAT) renewable water resource assessment, which is based on parameters such as precipitation, evapotranspiration, runoff, and soil moisture collected through surveys and other data collection methods (8, 3). More surprisingly, the Congo Basin has not attracted as much attention among the scientific communities as…

Reviewer #4 (Remarks to the Author):

Review for the manuscript entitled "Current availability and distribution of Congo Basin's freshwater resources" by Tourian, et. al.,

I was invited late to review this article. To provide an unbiased opinion, I carefully read the paper, and additional comments are still captured, and a thorough revision is required before the final recommendation.

We thank the reviewer for the assessment of our study.

Generally, the version I received does not have line numbers. Thus, in some instances, I quoted what I wanted to comment on. It is very hectic to provide comments on a version of a manuscript not lined-numbered.

We are sorry for the inconvenience. We now provide line numbers in the revised manuscript.

I have a major comment on what is referred to as a Drainable Water Storage Anomaly (DWSA), which was obtained by subtracting the LWSA and WWSA from the GRACE.
In general, GRACE Total Water Storage Anomaly (TWSA) is an integrated anomaly of all the changes in terrestrial water storage column in all forms including surface water storage, groundwater storage, and soil moisture storage. The two components utilized in this research (i.e., LWSA and WWSA) are part of the surface water storage, and to some extent soil moisture. Subtracting these two components will not lead to the DWSA. I cannot understand this?!!! At best these estimates would be a proxy of the groundwater storage. Please clarify more about that in the methodology section. More evidence is needed, and a clear reproducible methodology is required.

Firstly, we would like to stress that we agree with the statement of the reviewer that subtracting these two components (i.e., LWSA and WWSA) to GRACE Total Water Storage Anomaly (TWSA) would be a proxy of the variations of groundwater storage and soil moisture storage. These are indeed primary contributors to the river system. So, with the term Drainable Water Storage, we are referring to the storage compartments that determine the discharge rate of the river. To acknowledge this comment by the reviewer, we have modified the text:

Assuming that the lakes and wetlands are storages loosely coupled from the drainage system, we obtain Drainable Water Storage Anomaly (DWSA) for each sub-basin by subtracting the Lake Water Storage Anomaly (LWSA) and the Wetland Water Storage Anomaly (WWSA) from the Total Water Storage Anomaly (TWSA) (See Data and Methods). In essence, DWSA would be a proxy of the variations of groundwater storage and soil moisture storage, which are primary contributors to the river system.

Nevertheless, we would like to stress out that the term Drainable Water Storage has been largely discussed in the literature. We quote here Riegger (2020) to provide a comprehensive definition:

"*In contrast to discharge-less basins and/or arid areas, which are nearly exclusively driven by precipitation and evapotranspiration, the storage dynamics of catchments draining into a river system allows the hydraulically coupled storage compartments to be addressed via their contributions to river discharge. These comprise groundwater, surface water, the river network and temporarily inundated areas. All storages draining into the river system by gravity are referred to as "drainable" storage".*

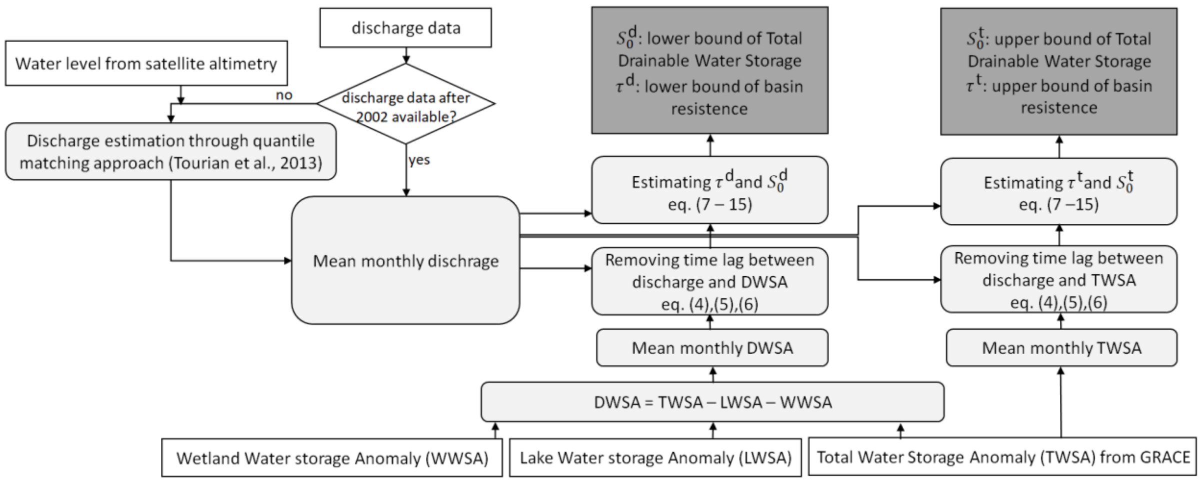
Under this definition, water stored in various storage compartments such as lakes and open surface waters, such as peatlands and wetlands, that lose the majority of their storage by direct evaporation and does not have any natural outlets or drainage channels could be categorized as decoupled storage. This means that the rate at which water is stored or released from these compartments may not directly influence the rate of river discharge.

However, in reality, it is true that these open surface water bodies are not completely decoupled from the drainage system. Therefore, the true drainable water storage is within the range of Total Water Storage Anomaly (TWSA) as seen by GRACE and DWSA (TWSA minus LWSA minus WSA). So the TWSA can be considered as the upper range of drainable water storage and DWSA is the lower range. This is why all our TDWS estimates are given as a range between the two estimates. We would like to draw your attention to the discussion section (lines 177–211):

To quantify DWSA, we have subtracted the storage anomaly of decoupled surface water bodies, e.g., lakes (LWSA) and wetlands (WWSA), from the GRACE total water storage anomaly. In reality, these open surface water bodies are not completely decoupled from the drainage system. Lake Tanganyika for instance partially drains into the Lukuga River at Kalemie, and further feeds the Lualaba basin (32). This discharge contributes to 18% of the total annual water loss of the lake, while its water balance is mainly governed by evaporation, corresponding to 82% of its total annual water loss (28). Similarly, Lake Bangwelu and its surrounding wetlands ultimately discharge into the Luapula River, Lake Mai-Ndombe and its wetlands contribute to the Fimi River, and Lake Mweru with its surrounding wetlands are drained by the Luvua River. Given these contributions into the river system, it can be argued that the storage anomaly of these water bodies should not be fully excluded from the total water storage anomaly. To examine the effect of removing the WWSA and the LWSA from the TWSA and its impact on the results, we estimate the same quantities by analyzing the relationship between river discharge and TWSA (Figure S5). Along with

the estimates from the DWSA-discharge relationship, Table 1 lists the estimates from TWSA-discharge relationship.
In this case, St0 and τ t differ from Sd0 and τ d for the entire Congo and for sub-basins of Lualaba-South, Lualaba-Lukuga, and Kasaï, as the lakes and wetlands are distributed among these three sub-basins (see Table S2 and Figure 1). Since all storage compartments are included in TWSA, the estimate of 139 ± 6 mm for St0, which corresponds to 502 ± 22 km3, can be considered an upper bound for the estimate of TDWS. On the other hand, since the wetlands and lakes in the Congo Basin have marginal outflows and contribute to the drainage system, the assumption that they are fully decoupled from the drainage system is not entirely true. Therefore, the estimated value of 476 ± 10 km3 for Sd0 can be considered a lower bound for TDWS. To this end, it is safer to express that the TDWS of the Congo Basin lies between 476 ± 10 km3 and 502 ± 22 km3. In Kasaï, the upper bound of the TDWS is 228 ± 18 km3 for which storage of wetland and Lake Mai-Ndombe are included in the estimation. In Lualaba-South inclusion of storage from wetlands and lakes Bangwelu, Upemba, and Mweru and wetland of Mweru Wantipa results in an estimate of 107 ± 5 km3 for the upper bound of TDWS (Table 1). Over the Lualaba-Lukuga, the TDWS with and without the storage of Lake Tanganyika varies between 20 ± 1 km3 and 40 ± 1 km3. In fact, if Lake Tanganyika would have been fully involved in the river system, its storage anomaly would result in an increased TDWS by 20 ± 1 km3 for the Lualaba-Lukuga sub-basin. Our results show that about 65% of Congo's total drainable water storage is stored in the southern part of the basin in the two sub-basins of Kasaï and Lualaba. The remaining 35%, is nearly evenly split between the middle Congo and the northern sub-basins Ubangui and Sangha.

To clarify this point and to better describe our methodology, we have included a flowchart in the manuscript describing all steps and illustrating that our estimate of TDWS is given as the range between lower and upper bound numbers.



Flowchart of estimating the upper bound and lower bound of Total Drainable Water Storage

Another major flaw is the spatial and temporal differences between GRACE and the other two estimates, more details are needed in the methodology section about the combination of these three ancillary products.

There are two approaches for subtracting the Lake Water Storage Anomaly (LWSA) and Wetland Water Storage Anomaly (WWSA) from TWSA: 1) subtracting from the corresponding GRACE grid and then aggregating over the basin or sub-basins, or 2) subtracting at the level of aggregated time series over the basin or sub-basins. The first method would face the problem of mismatch in resolution, as you have correctly pointed out. Therefore, to avoid this problem, we chose the second approach. That is, the LWSA and WWSA time series are subtracted from the TWSA time series that are aggregated over a basin or sub-basins. We have clarified this in the text to avoid confusion.

The obtained lake and wetland volume estimates (Figure S1 and Figure S2) are divided by the area of the corresponding sub-basin (Table S2) to obtain the Lake Water Storage Anomaly (LWSA) and Wetland Water Storage Anomaly (WWSA). For the quantification of Drainable Water Storage Anomaly (DWSA) we subtract the time series of LWSA and WWSA from the time series of GRACE based Total Water Storage Anomaly (TWSA). Note that there are two approaches for subtracting LWSA and WWSA from the TWSA: 1) subtracting them from the corresponding GRACE grid and then aggregating over the basin, or 2) subtracting them at the level of aggregated time series over a basin. The first method would face the problem of mismatch in resolution between the products (GRACE and satellite imagery). Therefore, the time series of LWSA and WWSA aggregated over a basin are subtracted from the aggregated TWSA time series of that basin.

Additional major comments are provided as follows,

Major comments,

Abstract,

The claim that the Congo River Basin's “freshwater availability remains highly unknown” is bold and unsupported.

Here we have referred to the fact that available total water storage and its distribution is poorly known, which remains actually true for most of the basins around the world. For the Congo, this is particularly emphasized by Alsdorf et al. (2016): *So far, the Congo River Basin is one of the least studied major river basins and little is known about its hydrology and hydrodynamics.*

We toned down the sentence by using relatively instead of highly and added the word “distribution”.

However, its freshwater availability and distribution remain relatively unknown .

Introduction,

The claim that the Congo basin is “Surprisingly, the Congo Basin has not attracted as much attention among the scientific communities as done for other large tropical river basins and remains relatively understudied (4), currently leaving an insufficient knowledge of its hydrology characteristics (8)" this is also very surprising. A naïve search on the web of science or google scholar will prove the opposite in terms of the Congo basin hydrology.

We are not claiming that there is no research done on the Congo River basin, but relatively to other large river basins, the Congo River basin remains understudied. This is well documented for instance in Alsdorf et al., 2016 in such as in the Table 1:

Table 1. Numbers of Peer-Reviewed Papers in Selected Hydrology or in Selected Earth Science Journals [a]

Journal Name	Congo	Amazon
Geophysical Research Letters	4	34
Hydrological Processes	3	50
Hydrology and Earth Systems Sciences	0	9
International Journal of Remote Sensing	3	18
Journal of Geophysical Research	9	71
Journal of Hydrology	7	42
Nature	1	14
Remote Sensing of Environment	2	17
Science	0	4
Water Resources Research	4	40
Totals	33	299

[a] Searches conducted December 2013 for all previous dates available in a given journal's online database. Search criteria were for the words "Congo," "Zaire," or "Amazon" in the titles or in the abstracts (Congo and Zaire numbers are combined in the Congo column). Resulting papers were further investigated for having significant discussion on hydrology, climate, or biogeochemistry of the particular basin. Table is representative, not comprehensive of all papers.

We agree that recent research has shed light on the importance of the Congo region, highlighting its unique biodiversity and the important role it plays in the global carbon and water cycles. However, despite recent advances in our understanding of the region, it remains largely understudied as compared to the Amazon basin.

Before introducing GRACE, you could introduce other remote-sensing hydrological sensors, or just make the reader ready for this transition from the lack of in-situ data to the abundance of hydrological satellite-based sensors.

We have modified the text accordingly.

While the Congo Basin was a relatively well-gauged basin prior to 1960, today only a few active hydrological gauges exist across the basin (4, 8). Therefore, understanding the major factors controlling the basin's freshwater variability at proper space and time scales remains a significant challenge. The lack of data has became less pronounced in the last two decades due to the availability of spaceborne observations on surface water characteristics through satellite altimetry missions e.g TOPEX/Poseidon, Jason-series and remote sensing missions like MODIS and Landsat (17, 18). Additionally, the Gravity Recovery and Climate Experiment (GRACE) and GRACE Follow-On satellite gravimetry missions provide unique estimates of continental water storage variability (19, 20).

Result,

The authors claimed that "since the wetlands in the Cuvette Centrale are fully connected to the river system (27), their storage should not be removed from the TWSA to obtain DWSA". Therefore, TWSA of these three basins can be equally considered as DWSA." As I introduced first, it is well-known that GARCE is a sum of various components since there are no wetland/river systems, GRACE anomaly cannot be only considered as DWSA. This claim is incorrect. I would consider them as related to groundwater storage anomaly, for instance.

This comment is related to the first major comment of R#4, to which we have responded in detail, providing all the information regarding TWSA and DWSA. Please see our response above.

Fig.2 units are missing.

Added.

Fig. 3 what do these arrows refer to?

They refer to the direction of hysteresis relationship between DWSA-discharge in consecutive months. We have added a detailed explanation in the text. For clarity, we now refer to the arrows in the text.

Following the DWSA-discharge relationships of mean monthly values shown as scatter plots in Figure 3 and as time series in Figure 4 (left), we observe that the Congo Basin, unlike the Amazon (25), generally exhibits a clockwise hysteresis (shown in Figure with light blue arrows). The clockwise behavior indicates that the storage time series lags behind discharge (Figure 4 bottom right). Note that here we deal with storage level and not the storage change (derivative of the storage) as a flux. While the catchment shows a clockwise relationship, February–May presents a counteracting behavior. This is also seen in the southern sub-basins of Kasa ̈i, Lualaba-North and Lualaba-South and originates from excess precipitation during the rainy season in the headwaters of these sub-basins (Figure 4). Such a precipitation pattern in the south also causes most lakes to *reach their maximum storage capacity. The WWSA and LWSA time series of the Congo Basin in Figure 2 (bottom) show its peak values between March and May.*

Fig. 4 I am very confused about the fig caption. What is "left" and what is "right" in the fig. caption?

The caption of the figure has been modified and a legend is added. A different symbol is used for clarity:.

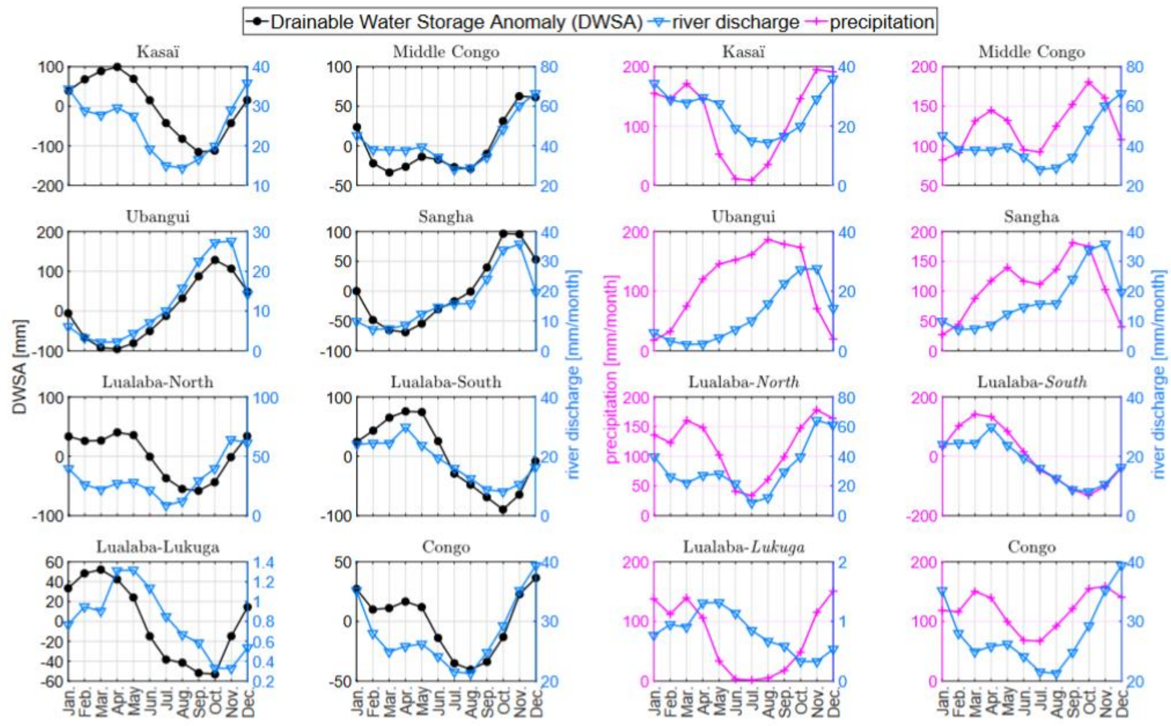


Figure 4: Column 1 and 2) Mean monthly river discharge and mean monthly Drainable Water Storage Anomaly (DWSA = TWSA − WWSA − LWSA) for Congo and its sub-basins. Note that mean monthly refers to mean of all Jan., of all Feb. etc. Mean monthly discharge values were obtained from discharge time series available over different time periods (see S2). DWSA mean monthly values were obtained from time series from 2002 to 2015 for Kasaï, Lualaba South, and Congo, and 2002 to 2017 for the other sub-basins. Column 3 and 4) Mean monthly precipitation over Congo and its sub-basins from Global Precipitation Climatology Centre (GPCC) dataset (33) averaged over 1990–2019 together with mean monthly river discharge time series.

I thought the Fig is showing the correspondence between Q and DWSA that is only good at four basins. The rest is very inconsistent.

Please note that the two time series that are temporally lagged might appear to be inconsistent. However, as described in the text, the relationship looks linear after removing the time lag, as shown in Figure 3.

Where is the GPCC came from? Also, can you add a legend for the two lines? And please use different line symbols, not only color.

As described in the data Section and in the Supplementary Materials, we obtain precipitation data from the Global Precipitation Climatology Centre (GPCC) and we use them for interpretation. This is now clearly described in the main text. The Figure has also been improved as shown above.

Methodology

Temporal length of GRACE observation not provided.

The time period has now been added.

The utility of the ITSG-2018 is not verified? Or at least compared against other products. It is well-known that different GRACE products will have different estimates. And, in terms of providing drainable water storage in a basin, every single GRACE product will introduce a different figure.

Indeed, it would be interesting to make such a comparison between data sets, but this comes at the cost of losing the main focus of the manuscript. Kvas et al. (2019) has performed an extensive comparison of the various products and they concluded that ITSG-Grace2018 slightly outperforms other available solutions in terms of the noise of mid-to-high degrees spherical harmonics.

To obtain TWSA from GRACE for the time period of 2002–2017, we use the spherical harmonic coefficients from the Institute of Geodesy at Graz University of Technology (ITSG)-Grace2018, which outperforms other available solutions in terms of the noise of mid-to-high degrees spherical harmonics (51, 52).

Kvas, A., Behzadpour, S., Ellmer, M., Klinger, B., Strasser, S., Zehentner, N., & Mayer-Gürr, T. (2019). ITSG-Grace2018: Overview and evaluation of a new GRACE-only gravity field time series. Journal of Geophysical Research: Solid Earth, 124(8), 9332-9344.

Another very obvious limitation is the Lake water volume, the hydroweb website provides the Lake water height as a single water height estimate for some selected Lakes across a basin. To convert the estimates to Lake volume water integrated lake area should be introduced, which I suspected that areal estimation came from the HydroSat source. More clarification is needed for reproducibility.

We had a detailed discussion on this issue in the supplementary material. In the revised manuscript, since this is indeed important, we have decided to transfer it to the main text of the manuscript

We estimate the monthly lake volume anomaly for Lake Mweru, Lake Upemba, Lake Bangwelu, Lake Tanganyika, Lake Kivu and Lake Mai-Ndombe, which are located in the Lualaba-South, the Lualaba-Lukuga, and the the Kasaï (see Figure 1 and table 3) by combining time series of surface water extent and water levels of the lakes provided by the HydroSat database (62) and accessible at http://hydrosat.gis.uni-stuttgart.de and the Hydroweb, accessible at https://hydroweb.theia-land.fr.

Table 3: Lakes in the Congo Basin

[redacted]	Basin	Average lake area [km^2]	Remote sensing product repository Lake water area	 Lake water level
Mai-Ndombe	Kasaï	2 305	HydroSat	HydroSat
Mweru	Lualaba-South	5 120	Hydroweb	Hydroweb
Upemba	Lualaba-South	11 730	HydroSat	HydroSat
Bangwelu	Lualaba-South	15 100	Hydroweb	Hydroweb
Kivu	Lualaba-Lukuga	2 380	Hydroweb	Hydroweb
Tanganyika	Lualaba-Lukuga	32 700	HydroSat	HydroSat

Note that Lake Tumba in the Middle Congo is not included in the analysis as Sentinel-3B is the only altimetry data available there as of mid-2018. However, according to Hydroweb, the amplitude of volume variation reaches a maximum of 0.5 km3, which is within GRACE noise and can be neglected for DWSA estimation.

Also, converting the Lake water height/volume??? to the anomaly is not clear. How did you do this? And how is this compared to the TWSA from GRACE?

To obtain TWSA from GRACE data, we use 2004–2009 as the reference period, during which the quality of GRACE data is assured. Accordingly, to preserve the consistency, in order to obtain the Lake Water Storage Anomaly and Wetland Water Storage Anomaly, we use the data between 2004 and 2009 as the reference. This is now clarified in the revised manuscript:

LWSA:

The Lake water volume anomaly is then obtained by a numerical integration of obtained ΔV. To ensure consistency with respect to the reference period for determining anomaly values, similar to GRACE TWSA, data from 2004 to 2009 are used as a reference.

WWSA:

Note that for each pixel, the SWS is computed in reference to the minimum surface storage obtained over the period of observations. For each wetland, we then isolate the SWS variations and remove the long-term mean of 2004–2009 (to be consistent with TWSA and LWSA) to obtain the Surface Water Storage Anomaly (SWSA). Figure S2 shows SWSA time series over the selected wetlands Mai-Ndombe (18550 km2), Bangwelu (30150 km2), Mweru (10820 km2), Mweru Wantipa (4640 km2) and Upemba (12370 km2) for the period 1992—2015 in km3. With the exception of the Mai-Ndombe wetland, which is in the Kasaï sub-basin, the rest are in Lualaba-South, covering an area of 57980 km2. For Lualaba-South, we sum the SWSA time series from Bangwelu, Mweru, Mweru Wantipa, and Upemba, remove the long-term mean of 2004–2009, and then divide it by the area of Lualaba South to obtain Wetland Water Storage Anomaly (WWSA) in terms of equivalent water height (Figure 2). Over Kasaï sub-basin, WWSA is determined by dividing the SWSA of Mai-Ndombe wetland by the area of Kasaï sub-basin (Figure 2).

The SWE component is a grided 0.25 x 0.25 and the native spatial resolution of GRACE is 3 x 3 degrees, how both are combined in the drainable water estimation?

Please see our response to your second major comment: There are two approaches for subtracting the lake Water Storage Anomaly (LWSA) and Wetland Water Storage Anomaly (WWSA) from the TWSA: 1) subtracting from the corresponding GRACE grid and then aggregating over the basin, or 2) subtracting at the level of aggregated time series of a basin. The first method would face the problem of mismatch in resolution, as you have correctly pointed out. However, to avoid this problem, we chose the second approach. That is, the LWSA and WWSA time series are subtracted from the TWSA time series. We have clarified this in the text to avoid confusion.

Also, at a temporal scale, GRACE and SWE should have produced relative to the same baseline anomaly. How did you do that? Similar limitations apply to the rest of the datasets.

Yes. This is ensured by taking 2004–2009 as the same baseline anomaly for all datasets. Please see our response to your comment above.

For the estimation of Total Drainable Water Storage and basin resistance, in this section the authors claimed to use the monthly mean value from GRACE and Q, are the data available in the sub-monthly format, especially GRACE???

We think there is a mis-understanding here. With the term "mean monthly" we refer to the mean value of all January values for the January etc. So practically, we considered what is shown in Figure 4. We made it explicit in the text to avoid confusion.

Minor comments

Gt. Abbreviation not pronounced at first.
Corrected. Gigaton.

11th Apr 23

Dear Dr Tourian,

Your manuscript titled "Current availability and distribution of Congo Basin's freshwater resources" has now been seen by our reviewers, whose comments appear below. In light of their advice I am delighted to say that we are happy, in principle, to publish a suitably revised version in Communications Earth & Environment under the open access CC BY license (Creative Commons Attribution v4.0 International License).

We therefore invite you to revise your paper one last time to address the remaining concerns of our reviewers. At the same time we ask that you edit your manuscript to comply with our format requirements and to maximise the accessibility and therefore the impact of your work.

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We hope to hear from you within two weeks; please let us know if you need more time.

Best regards,

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REVIEWERS' COMMENTS:

Reviewer #1 (Remarks to the Author):

My comments have been addressed fully.

Also, I have been asked for review their response to reviewer #4. I think most of the comments from Reviewer#4 have been addressed carefully. I have little concern about the response to the major comment 1 (p.3-4). It is nearly sufficient, and I appreciate the flowchart. I think the authors might still need to explain why it can be assumed that lakes and wetlands are decoupled from the drainage system by refereeing to the literature with quantifications or shows their analysis, especially for the wetland. As stated, “since the wetlands in the Cuvette Centrale are fully connected to the river system (27)”, how about the entire Congo Basins? For example, whether they are permanent wetlands, and what is the residence time of the entire WWSA.

Reviewer #4 (Remarks to the Author):

This revised version reads much better and the authors have addressed all my comments properly. No further comments from my side.

Dear Editor and Reviewers,

Please find enclosed our point-by-point response to the reviewers' comments on the manuscript entitled "Current availability and distribution of Congo basin's freshwater resources" that we submitted as a contribution to *Communications Earth & Environment*.

With respect to the detailed responses, the reviewers' assessments appear below in black and we highlighted our answers in blue. We believe we have addressed each comment carefully and hope that the responses meet your expectations.

Best Regards,

Mohammad J. Tourian, on behalf of all authors

Reviewer #1 (Remarks to the Author):

My comments have been addressed fully.

We are overjoyed that we have thoroughly addressed all of the first reviewer's comments

Also, I have been asked for review their response to reviewer #4. I think most of the comments from Reviewer#4 have been addressed carefully. I have little concern about the response to the major comment 1 (p.3-4). It is nearly sufficient, and I appreciate the flowchart. I think the authors might still need to explain why it can be assumed that lakes and wetlands are decoupled from the drainage system by refereeing to the literature with quantifications or shows their analysis, especially for the wetland. As stated, "since the wetlands in the Cuvette Centrale are fully connected to the river system (27)",

Thanks for your comment. We addressed this relevant comment by referring to the recent work by Kitambo et al., (2022) who showed a strong temporal correlation between the surface water extend of middle Congo floodplain and river discharge of the Congo at the Brazzaville/Kinshasa station. Such a strong temporal variation is explained by variations in surface water extent in the Cuvette Centrale region, which suggests that the wetlands in the Cuvette Centrale are mostly connected to the river system:

In essence, wetlands and natural lakes can store and release water independently of river flow and have a high water-holding capacity allowing them to store water for extended periods of time, even during periods of low or no river discharge (28). In fact, DWSA would *be a proxy of the variations of groundwater storage and soil moisture storage, which are primary contributors to the river system. As shown in Figure 1, there are no major lakes or wetlands in the Ubangui, Middle-Congo, and Sangha sub-basins, which means that no LWSA or WWSA is subtracted from TWSA. The Cuvette Centrale region, composed of forests and wetlands, extends into these three sub-basins. Recent findings by (18) indicate a strong temporally correlated influence of the middle Congo floodplain on Congo basin discharge at the Brazzaville/Kinshasa station, for which a substantial part of the variability is explained by variations in surface water extent in the Cuvette Centrale region. Such an influence suggests that the wetlands in the Cuvette Centrale are mostly connected to the river system (29), which means that their storage should not be removed from the TWSA to obtain DWSA.*

… how about the entire Congo Basins? For example, whether they are permanent wetlands, and what is the residence time of the entire WWSA.

This is a very good point. The sub-basin Lualaba-South hosts some permanent wetlands. We have addressed this comment by adding following paragraph to the text.

Over the Lualaba-South with the permanent wetlands and lakes of Bangwelu, Mweru, Mweru Wantipa and Upemba, the time constant τ_d is 7.7 ± 0.2 months. Such a value turns into a relatively larger time constant τ_t of 13.9 ± 0.9 months when the storage of these open surface waters is considered as fully coupled compartments in the drainage system. These results imply that water stored in the permanent wetlands and lakes in Lualaba-South impose an extra resistance time of about 6.2 ± 0.9 months with about 5 months due to the wetlands and rest due to the lakes. Furthermore, Lake Mai-Ndombe and its surrounding wetland explain the large τ_d of 9.3 ± 0.2 months and τ_t of 10.1 ± 0.8 months in the Kasaï. *These results imply that water stored in the permanent wetlands and lakes in Lualaba-South impose an extra resistance time of about 6.2 ± 0.9 months with about 5 months due to the wetlands and rest due to the lakes. Furthermore, Lake Mai-Ndombe and its surrounding wetland explain the large τ_d of 9.3 ± 0.2 months and τ_t of 10.1 ± 0.8 months in the Kasaï.*

B. Kitambo, F. Papa, A. Paris, R. M. Tshimanga, S. Calmant, A. S. Fleischmann, F. Frappart, M. Becker, M. J. Tourian, C. Prigent, and J. Andriambeloson, "A combined use of insitu and satellite-derived observations to characterize surface hydrology and its variability in the Congo river basin," Hydrology and Earth System Sciences, vol. 26, no. 7, pp. 1857–628 1882, 2022.

Reviewer #4 (Remarks to the Author):

This revised version reads much better and the authors have addressed all my comments properly. No further comments from my side.

We are delighted that we have successfully incorporated all of the reviewer #4's comments.