Response Letter
essd-2023-417

We would like to thank the Editor for the editorial management of our work, and the referees for providing insightful reviews. We have prepared detailed point-to-point answers for each comment raised, and have incorporated the changes into our revised manuscript.

Referee 1 (Polina Lemenkova)

We are grateful for Referee 1's heartening feedback.

Thank you very much for spending the time to review our manuscript.

Referee 2 (Anonymous)

Wei et. al. unified dams in Mekong River basin from different sources, leading to a total number of 1,055 dams in the dataset. Relied on the dams' locations and simulated discharge, they assessed the total hydropower potential spatially. Water management has significant impacts on hydrological cycle. Therefore, this dataset is very helpful for hydrological and Earth system modelers to include dams into the simulation to better understanding the potential impacts.

We are thankful for Referee 2's encouraging comments. We have addressed all of Referee 2's suggestions in points 1 to 13 below. The changes include adding two new dam attributes, adding a geographic plot to Figure 1, clarifying all issues highlighted in the methods section, and expanding the future hydropower calculations to 2040 (including editing Figure 6).

1. Although this dataset archives the most comprehensive number of dams in Mekong River basin, I found some important characteristics are not included, which I wonder if they can be derived or not. For example, area-volume relationship, operation rules, and dependent area are not available in this dataset. Those characteristics are needed to run water management module in river transport model.

   We appreciate the usefulness of adding such characteristics to the database, but unfortunately there is insufficient data available to source for or derive these characteristics in the Mekong basin.

   Deriving the area-volume relationship would require altimetric data or instrumental measurement of water levels, but the availability of altimetric data is restricted by satellite coverage, while instrumental measurement of water levels is not available for most Mekong dams. Moreover, our database contains many small dams, and their reservoir areas are too small to be mapped from Landsat data. It would also be difficult to accurately calculate the regression equation between the two variables, as the relationship can be linear or non-linear depending on many factors, such as the valley morphology at each dam. To address these challenges in deriving the area-volume relationship would be beyond the scope of our paper.

Information regarding dam operation schemes, especially operation rules and the downstream demands met by a dam, is not publicly available for most dams in the Mekong Basin (Dang et al., 2022). This is due to the sensitive nature of such information in a transboundary river basin, particularly for China and Laos. Dam operation rules can also be subjected to constant changes, depending on the needs at each point in time. Including this highly variable attribute in our database could diminish the accuracy of the data we provide, and potentially mislead those using our database.

The dependent area of a dam has been defined as the “number of cells downstream either to the next reservoir, the river mouth, a predefined maximum number of downstream cells (e.g. 5 cells at 0.5˚ or 10 cells at 1˚, corresponding to the typical distance that river water travels within a month), or grid cells which are located at a predefined threshold distance from the main river reach (e.g. 200 km or 2˚)” (Vanderkelen et al., 2022). Since distance is defined differently in each study and the dependent area calculated varies with the distance defined, we did not include it as a dam attribute in the database.

Nevertheless, we have added two new attributes to our database: degree of regulation and plant factor. Degree of regulation, derived from reservoir volume and discharge, estimates the impact of dams in altering downstream discharge and the natural flow regime, which could be useful in determining the inflow at downstream dams and its influence on dam operation schemes (Mailhot et al., 2018). Plant factor, sourced from a Mekong River Commission report, represents the ratio between actual and theoretical hydropower output, from which the capacity a dam is operating at can be inferred (MRC, 2016). Our data can be utilized by other researchers in deriving the information needed to address their specific research aims.

We have included these two attributes in the manuscript, line 183: “Including the remaining attributes in the 18 dam databases, such as dam height, dam length, reservoir volume, and plant factor (ratio between actual and theoretical hydropower output), the dam attributes are…” and line 203: “Degree of regulation is derived from the ratio between total upstream reservoir volume and discharge at each dam, which represents the impact of the dams on downstream flow regime (Grill et al., 2014; Lehner et al., 2011).” We have updated Table 2 on the list of dam attributes.

2. I appreciate the analysis of the hydropower potential, but I wonder if the authors can use the new dam dataset in river routing model (e.g., CaMa-Flood) to assess the impacts of dams on streamflow variations. This will further demonstrate the application of the new dataset.

Indeed, we are in the process of incorporating the new dam database into the CaMa-Flood model; however, given that the current reservoir operation scheme is designed to simulate large dams/reservoirs, we have applied a filter to select large dams that existed during our simulation period. The filtering criteria include: (1) dam height is at least 15 m (≥15 m), (2) storage capacity is over 1 million cubic meters (Mm3), and (3) energy generation capacity is over 100 Megawatts (MW). Therefore, the final number of dams with these filters, when the same criteria are applied, will remain largely the same. To fully utilize the new database, it is essential to update the reservoir scheme to simulate smaller reservoirs and extend our simulation period to recent years, which is currently underway and the results will be presented in our forthcoming publications.

3. Line 112 – Line 122: I think referring to geographic plot (e.g., Figure 3) will be very useful for the reader to figure out the location of Mekong River basin.

   We have added a geographic plot to Figure 1 (as Figure 1B), and referred to it in the text: "The Mekong Basin of 795,000 km^2 is shared across six countries (Gao et al., 2022) (Fig 1B)."

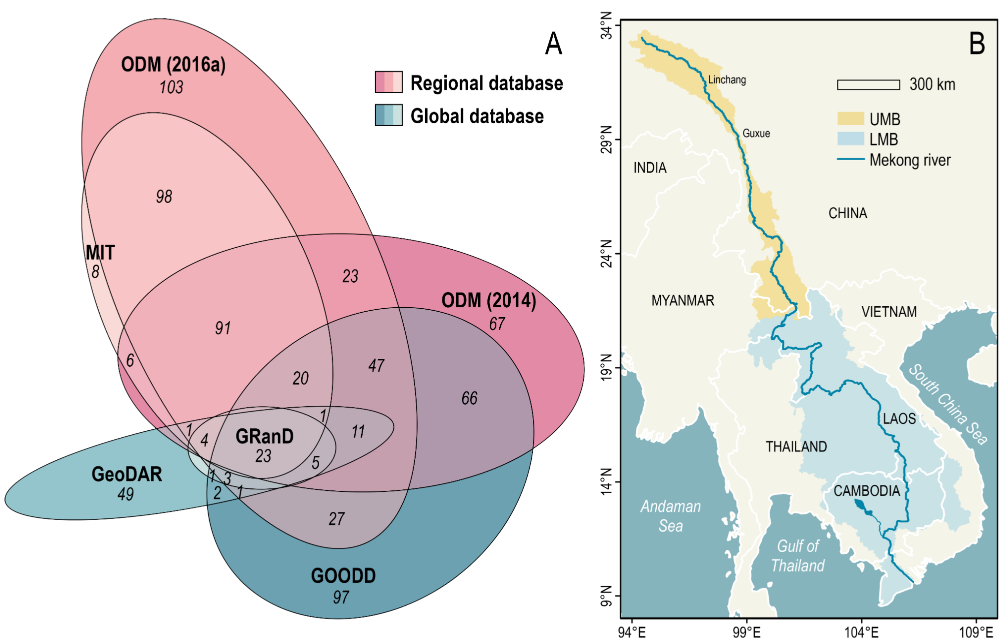


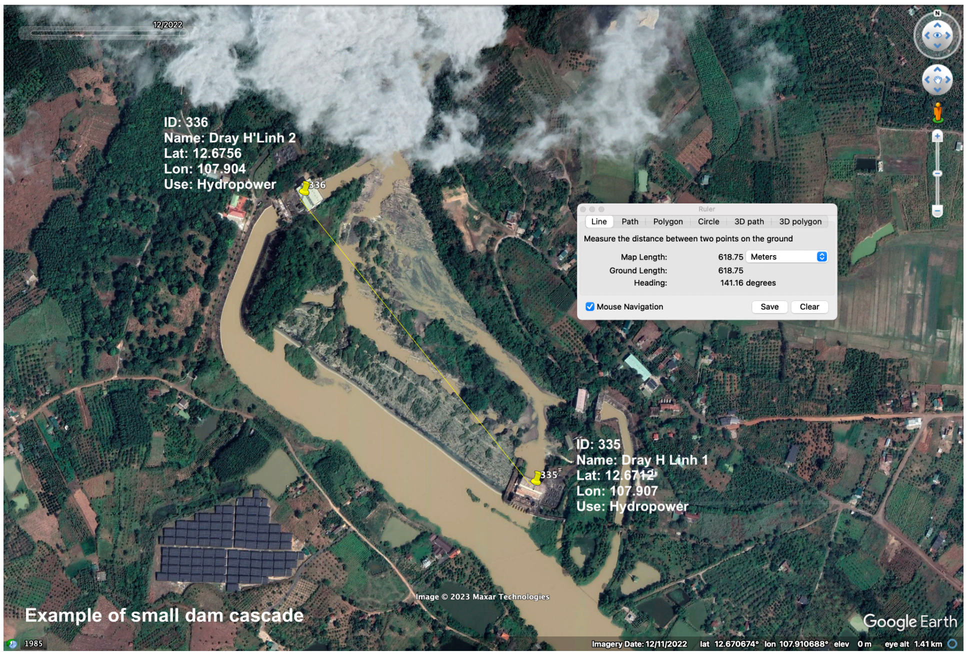
Figure 1. A. Venn diagram illustrating the overlaps and differences across six main databases. The pink ellipses are regional databases, while the blue ellipses are global databases, corresponding to the color scheme in Fig. 2. B. Map of the Mekong Basin, split into the Upper Mekong Basin (UMB) and Lower Mekong Basin (LMB).

4. Line 155: I wonder if larger buffer should be used. Is it feasible to have two dams within a few hundred meters?

   We agree that large dams would lie further apart, but our database includes many small dam cascades and irrigation dams, which can lie within a few hundred meters apart. Moreover, the 100m buffers of each coordinate cluster overlap to form a wider buffer zone (Figure 2 step 2).

Hence, 100m was chosen to avoid the merging of small dams. To account for any duplicate points of large dams: "Dam entries are merged based on same/similar names through a manual check in excel. … Coordinates of operational dams are validated using satellite imagery in Google Earth… multiple coordinates referring to the same dam are merged" (lines 159 to 160 and lines 168 to 169).

To clarify this issue, we have edited lines 156 to 157: "100m was chosen after plotting buffers of different sizes and comparing them against the sizes of coordinate clusters, and to avoid the merging of closely spaced irrigation dams and small dam cascades."



5. Line 195: There are three stream order classifications in HydroRIVERS. The authors need to clarify which classification was used here.

   We have added the clarification: “Strahler stream order”.

6. Line 195: Which level of HydroBASINS was used here?

   We have added the clarification: “HydroBASINS (Level 7), merged with reference to the Mekong River Commission’s sub-basin delineation”.

7. Line 198: Are only the dams without sub-basin from HydroBasins were delineated for the contributing area here? Please also clarify which method is used for computing flow direction and accumulation.

   HydroBasins was used to identify the general sub-basin each dam lies in for discussions on the spatial distribution of hydropower (Fig. 5), but not the specific catchment area of each dam because the dams are not the pour points in HydroBasins. Thus, the catchment area was delineated for all dams, including both the unnested and nested catchment areas (line 200).

   To clarify this issue, we have edited line 197: “we use GIS to compute the attributes of all dams instead”.

   We have added the clarification: “flow direction and accumulation are derived from the DEM using the D8 flow method”.

8. Line 201: Is the mean annual discharge from model simulation or observation. Why was CHIRPS selected for the mean annual rainfall? If the mean annual discharge is from model simulations, I would suggest use the same precipitation that drive the river model for the mean annual rainfall.

   We have added the clarification: “modeled mean annual discharge”.

   The CaMa-Flood model was driven by runoff simulated by the global hydrological model HiGW-MAT, and the data used to force HiGW-MAT is at 0.5 degree (Dang et al., 2022; Pokhrel et al., 2017). CHIRPS is of a higher resolution (0.05 degree) and is the most widely used rainfall product across various research purposes, thus we found it more meaningful to choose the best available data for rainfall and for discharge, rather than focusing on having consistency between rainfall and discharge data.

   Furthermore, as the trend in modeled discharge across the countries is compared with the trend in rainfall (Fig. 4E and 4F), presenting the model input (rainfall) and model output (discharge) of

Dang et al. (2022) could introduce bias in the comparison. By choosing a different rainfall product, we seek to avoid any potential bias, and to verify that the distribution pattern in rainfall on a basin-wide scale is similar across different products.

To clarify this issue, we have edited line 202: "mean annual rainfall from CHIRPS, a widely used product at 0.05 degree resolution (CHIRPS, 2023)" and line 310: "Likewise, since discharge is dependent on the available rainfall, a similar trend can be seen between rainfall and discharge, even though the rainfall data presented is not the rainfall data used to model discharge. This suggests that the trend is not due to any potential bias introduced by modeling, and that the distribution pattern in rainfall on a basin-wide scale is similar across different products.".

9. Line 236: In my understanding, ISIMIP2b archives the future atmosphere forcing projections. Do you mean the future discharge is simulated by WaterGAP2 forced by ISIMIP2b projections? Please also clarify which emission scenario and climate model were used. I suggest the author clarify the paragraph between Line 232 – Line 242. Specifically, how CaMa-Flood is setup (is inundation mode turned on, which runoff is used to drive the simulation)? How is the future discharge simulated?

   Yes, we mean that the future discharge is simulated by the WaterGAP2 model for the ISIMIP2b simulation round.

   The emission scenarios used are RCP 2.6, 4.5, 6.0, 8.5 (line 239).

   We have edited lines 232 to 242 to provide more clarification: "... We calculate hydropower potential using present-day discharge simulated by the CaMa-Flood model (2011-2015, 0.05 degree), with inundation mode turned on and driven by runoff simulated by the global hydrological model HiGW-MAT (Dang et al., 2022; Pokhrel et al., 2017). Future discharge is simulated by the WaterGAP2 model for the ISIMIP2b simulation round (2021-2040, 0.5 degree), using the GFDL-ESM2M climate model (Gosling et al., 2023). … We perform one calculation per RCP, and for each calculation, …".

10. Since the historical and future discharge are simulated by different models and different spatial resolutions, the difference may be caused by model uncertainty instead of climate change. Then the question is why not use the ISIMIP2a projected runoff to drive CaMa-Flood for the future discharge? Then, the uncertainty of model structure can be cancelled.

   We agree that the seasonal patterns in discharge may vary between the results from running the CaMa-Flood model with WaterGAP2 model (ISIMIP2b) and results from the WaterGAP2 model. However, our discharge calculations focus on the total annual discharge averaged across several years, which would be largely similar across the models. Although the ISIMIP2b simulations are limited by their resolution (as noted in lines 365 to 368), the ISIMIP2b simulations were chosen because they are bias-corrected and expected to provide reasonable projections (Hempel et al., 2013; Pokhrel et al., 2021).

To clarify our choice of data, we have edited line 237: “ISIMIP2b simulations are bias-corrected, and WaterGAP results have been used and validated globally (Gudmundsson et al., 2021; Hempel et al., 2013; Pokhrel et al., 2021). Datasets from both the CaMa-Flood model and the WaterGAP2 model consider the effect of dams on total annual discharge.”

11. Line 290 – Line 304: Does the total hydropower capacity are from all the 661 operational dams, including the non-hydropower dams? I am a little confused about the definition of total hydropower capacity, theoretical hydropower potential, and installed hydropower potential. Please clarify the definitions in the method section, and describe which dams are used to estimate them.

    We have edited lines 213 to 215 to define total or installed hydropower capacity: “Using the year of completion (and year of closure, if any), dams are filtered by decade – 1980s, 1990s, 2000s, 2010s, post-2020s. The first four groups include dams that are operational in each decade, while the last group includes dams that began operation in 2020 or later, dams under construction, and planned dams with available information. Canceled dams are excluded from analysis. The total or installed hydropower capacity is calculated per decade, defined as the sum of the hydropower capacity of all hydropower dams in each decade.”

    We have also added the definition of theoretical hydropower potential to line 224: “To calculate the theoretical hydropower potential, defined as all hydropower potentially available, including hydropower that has yet to be harnessed, ...”.

12. Line 362: I don’t think future projections can be used to predict the discharges changes for the next decade (e.g., 2021-2030). This is because climate model projections are commonly used to understand the long-term changes, and cannot be used for short-term predictions.

    Line 376 – Line 384: Due to the relatively short projection period, the differences of the changes among different emission scenario may cause by natural variability instead of CO2 emission.

    We have expanded the future hydropower calculations to 2021-2040, to predict the changes beyond the next decade and to increase the projection period to 20 years. We have edited Figure 6 to present the 20-year average.

    We have edited lines 376 to 383 to reflect the new values: “The hydropower potential distribution appears to be similar across the RCPs, but the total hydropower potential varies slightly with RCP – lower in RCP4.5 and 8.5, but higher in RCP2.6 and 6.0 (Fig. 6B to 6E). Matching this trend, hydropower potential in China and Laos are similar for RCP4.5 and 8.5, but higher in Laos for RCP2.6 and 6.0 (Fig. 6I). These observations could be associated with the greenhouse gas concentration in each RCP scenario during 2021 to 2040 – higher in RCP4.5 and 8.5, but lower in RCP2.6 and 6.0 (IPCC, 2014; Hanna et al., 2019). Interestingly, hydropower potential across the RCP scenarios remains generally constant in most of the countries, but changes significantly in Laos (Fig. 6G to 6J)."

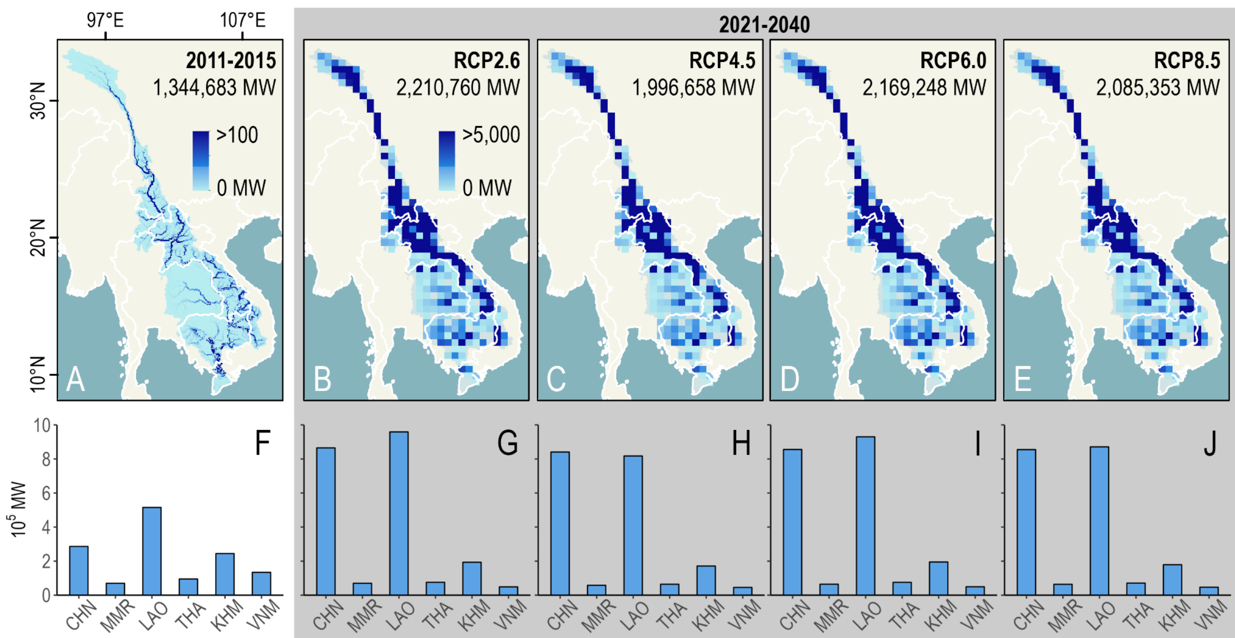


Figure 6. A. Theoretical hydropower potential in the Mekong Basin, estimated from gravity, elevation (relative to the downstream cell), and average annual discharge in 2011 to 2015. B-E. Hydropower potential estimated from average annual discharge in 2021 to 2040, modeled based on four Representative Concentration Pathways (B: 2.6, C: 4.5, D: 6.0, E: 8.5). F-J. Bar graph of the total hydropower potential in each country, corresponding to A-E.

13. Line 476 – Line 479: What results support this statement?

We have edited line 476: "With the highest projected dam growth in Laos and the environmental importance of Laos in the Mekong Basin, we suggest…".

Thank you very much for spending the time to review our manuscript.

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