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COMMENT • OPEN ACCESS

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ENVIRONMENTAL RESEARCH  
LETTERS

## COMMENT

## Comment on 'Changes of inundation area and water turbidity of Tonle Sap Lake: responses to climate changes or upstream dam construction?'

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E-mail: [marko.k.kallio@aalto.fi](mailto:marko.k.kallio@aalto.fi)**Keywords:** large river basin, flood pulse, hydropower operation, climatic changesSupplementary material for this article is available [online](#)**Abstract**

Recent hydropower development in the Mekong River has triggered a lot of discussion about its impact on flood dynamics along the river, as well as in one of the world's most productive lake-floodplain systems—the Tonle Sap Lake. A recent article by Wang *et al* (2020 *Environ. Res. Lett.* 15 0940a1) in this journal conclude that changes in precipitation have played a much larger role than the operation of hydropower dams, contradicting existing research. However, we argue that by using an annual mean discharge and inundation area Wang *et al* (2020 *Environ. Res. Lett.* 15 0940a1) ignore the fundamentals of the system: the difference between dry season water level and peak water level, and thus the extent of the flooded area, which is the key function of the flood pulse. Further, by using annual mean discharge authors are not able to capture the actual operation of hydropower dams, and thus their impacts. Hydropower dams consume very little water through evaporation, but shift the flow regime from wet to dry season. We show here that when taking into account the characteristics of the system, and analysing changes from anthropogenic impacts on low and high flows separately, dams play a central role in recent changes in the flood characteristics of the Mekong.

**1. Introduction**

Cambodia's Tonle Sap Lake (TSL) has been under intensive investigation for decades due to its unique character and importance to the Lower Basin of the Mekong River. In a recent publication in the *Environmental Research Letters*, Wang *et al* (2020) investigate the factors affecting the observed shrinking of the TSL's annual inundation area. The authors of the study find that the shrinking of the lake inundation area can be primarily associated with a reduction in precipitation in the Mekong upstream. They further conclude that the accelerating hydropower construction in the Mekong Basin—a topic which has been intensively debated—shows insignificant influence in the annual changes of the lake surface area. The authors touch a key issue in the development of the Mekong, and we welcome their contribution to this discussion.

We have, however, concerns relating to the methodology and data acquisition presented in Wang

*et al* (2020), and thus their findings and conclusions. In the following sections, we first briefly describe the TSL system and how upstream dams may affect it, and then address the key issues in Wang *et al* (2020) which may result in inability to capture the essentials of this highly complex lake system.

**2. The TSL system and the influence of upstream dams**

The TSL system is driven by an annual flood pulse resulting, in average, in a six-fold increase in water level and five-fold in surface area (Kummu *et al* 2014). The annual change is determined by the water level difference between the lake and the Mekong River: during the wet season, water level in the Mekong rises and the flow along the Tonle Sap River reverses and starts to fill the lake (and vice versa during the dry season). The water level of the TSL, and thus its flooded area, is closely related to the water level in the Mekong

mainstream—but other factors, such as the backwater effect from the Mekong Delta, affect it too.

Wang *et al* (2020) report a significant correlation between the annual mean inundation area and annual mean discharge in Kratie, the last station before the floodplains. However, by using annual mean discharge and inundation area, authors fail to address the key component of the flood pulse system, where the difference between low and high inundation area is the key driver of the floodplain productivity (Junk *et al* 1989, Lamberts and Koponen 2008). Further, when using annual mean discharges, Wang *et al* (2020) fail to take into account the impact of hydropower dams: as shown by the existing studies, hydropower dams on the Mekong decrease wet season discharge (water is impounded in reservoirs), and increase the dry season discharge (water is released from reservoirs) (Lauri *et al* 2012, Piman *et al* 2013, Räsänen *et al* 2017, Hoang *et al* 2019, Binh *et al* 2020, Yun *et al* 2020).

We show that the high flow (Q5) in Stung Treng (a station slightly upstream from Kratie, used here because its longer observation time series) correlates significantly (Spearman  $\rho = 0.84$ ,  $p < 0.0001$ ) with the high inundation area (Area5) of the lake. Unlike the high flows, low flows Q95 show no correlation with low inundation area (Area95) ( $0.08$ ,  $p = 0.69$ ) during 1997–2019, likely because of a change in the hydrological controls during this period (see figures 1(A) and (C)): Spearman  $\rho$  for 1997–2011 is  $0.50$  ( $p = 0.056$ ) and for 2012–2019 it is  $0.64$  ( $p = 0.096$ ), which suggests that the increasing dry season water levels may be becoming more important determinant of the lake minima (albeit, the number of observations is very small and thus, the correlations are highly uncertain).

We argue that to fully understand the linkage between changes in upstream hydrology, including hydropower dams, and the TSL inundation area, and climate change, a hydrodynamic model should be applied with the relevant boundary conditions, and the results of which analysed on a seasonal basis.

### 3. Issues pertaining to the data acquisition

Further related to the lake's inundation area, Wang *et al* (2020) ignore the flooded forest part of the floodplain. This is due to limited ability of their method that uses satellite images for capturing the area leading to an increase of only 50% of the inundation area in the wet season (considerably less than the observed increase of 500%; see figures 1(E) and (F)). The satellite derived inundation area reported by Wang *et al* (2020) also considerably differs from those reported in Tangdamrongsub *et al* (2016).

We used an approach by Kummu *et al* (2014), who developed a water level—area function based on a digital elevation model, to reproduce the lake's daily inundation area for 1997–2019. We detected a

small decreasing trend in low inundation area Area95 ( $-7.5 \text{ km}^2$  per year,  $p = 0.093$ ) and stronger decreasing trend in high inundation area Area5 ( $-128 \text{ km}^2$  per year,  $p = 0.039$ ) (figures 1(E) and (F)).

### 4. Trends in discharge

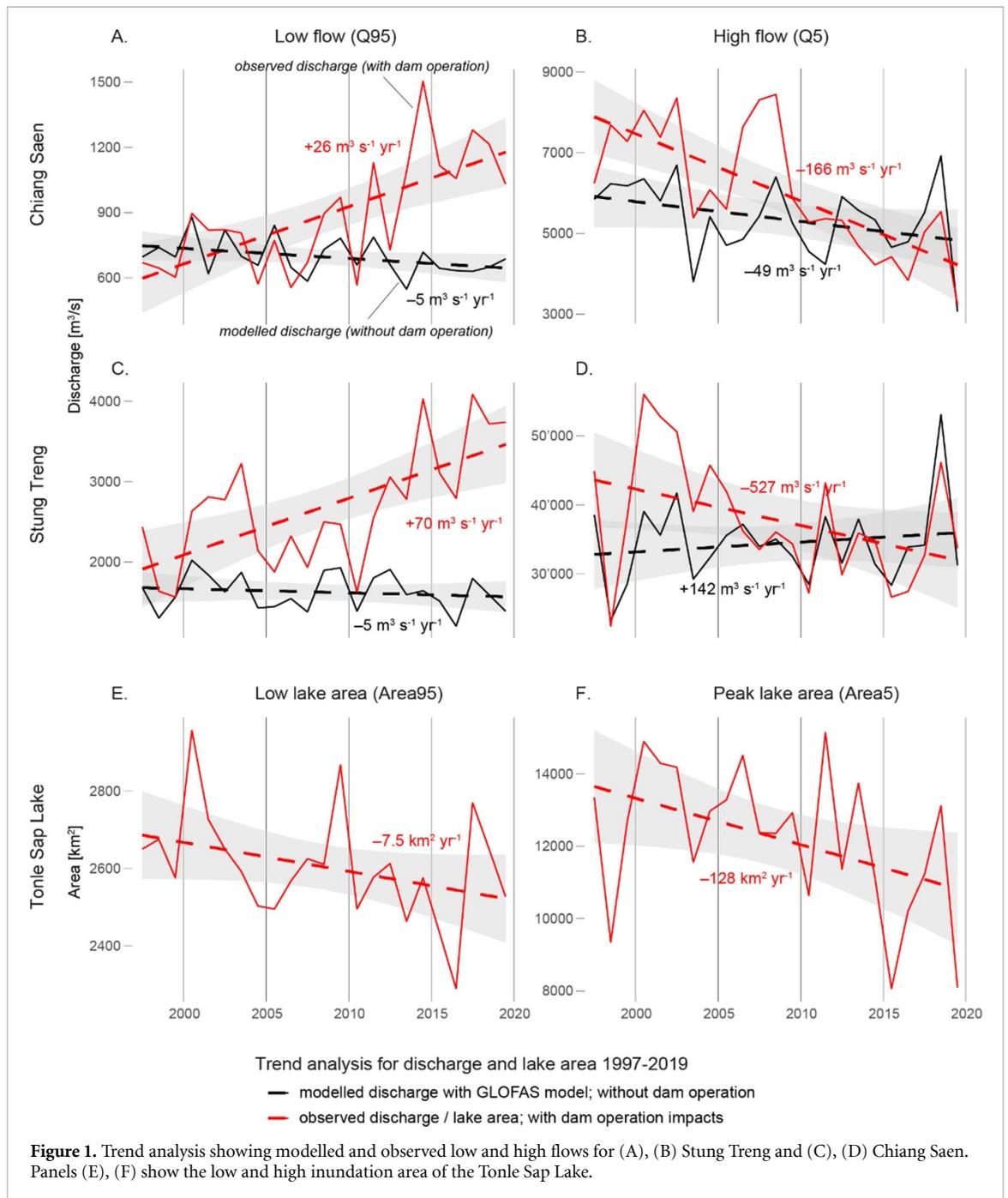
Wang *et al* (2020) report a significant decreasing trend in annual mean discharge in Kratie, and link this to decreasing trend in annual precipitation. However, as argued above, wet and dry season discharges should be assessed separately to understand the impacts on flood pulse. Further, Wang *et al* analysis period of 17 years (2000–2016) is on the limits for hydrological analyses because a few wet or dry years can potentially skew the trend.

To assess the discharge trend separately for high and low flows, in line with how the flood pulse system and the hydropower dam impacts are analysed, we used:

- observed discharges in Stung Treng and Chiang Saen (first station after Chinese border) for years 1980–2019
- discharges obtained from GLOFAS global streamflow reanalysis product for years 1980–2019 (Alfieri *et al* 2020). GLOFAS is based on landuse from 2009 and does not include recent hydropower development.

The use of modelled discharges allowed us first to assess the changes in discharge without anthropogenic drivers, such as hydropower operation. Therefore, when using both the modelled and observed discharges, we were able to disentangle the climatic and anthropogenic impacts on changes in discharge. We used 1980–1996 as a validation period, and found that GLOFAS reproduced the daily discharge very well in these two stations (NSE = 0.88 and 0.93,  $R^2 = 0.944$  and 0.975 for Chiang Saen and Stung Treng, respectively; see figures 1(A) and (C)). The timeseries were bias-corrected using the validation period. For the trend analysis, we extended the time period to the maximum possible, for which all the discharge data and lake inundation area were available, i.e. 23 years (1997–2019).

We found that in Stung Treng, high flow Q5 shows a positive trend in the modelled data, i.e. without dam operation ( $+142 \text{ m}^3 \text{ s}^{-1}$  per year), while observed discharge shows a strong negative trend ( $-527 \text{ m}^3 \text{ s}^{-1}$  per year) (figure 1(D)). In Chiang Saen the Q5 show considerably stronger decreasing trend for the observed timeseries than for modelled data ( $-49$  and  $-166 \text{ m}^3 \text{ s}^{-1}$  per year) (figure 1(B)). When looking at the low flow Q95, we found no significant trend in modelled data, while observed data shows strong increasing trends in both Stung Treng ( $-5$  and  $+70 \text{ m}^3 \text{ s}^{-1}$  per year) and Chiang Saen ( $-5$  and  $+26 \text{ m}^3 \text{ s}^{-1}$  per year) (figures 1(A) and (C)). The findings are similar for the analysis



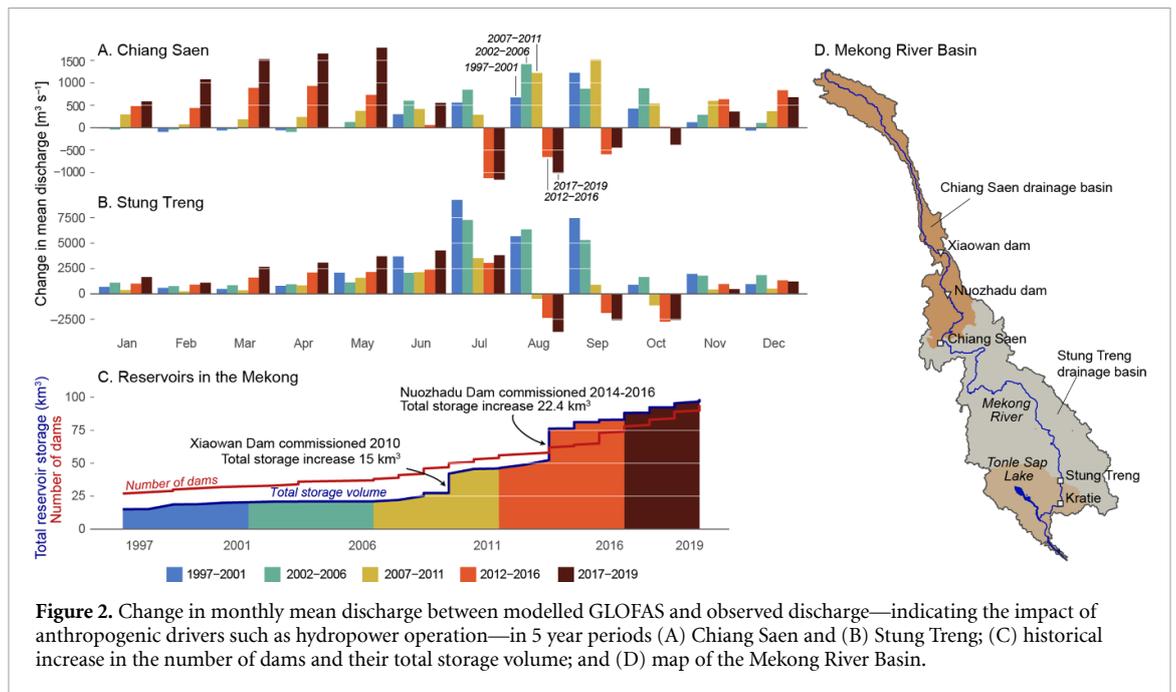
period 2000–2016, which was used by Wang *et al* (2020).

We further assessed the monthly changes in discharge due to the anthropogenic drivers in these two locations, and found that the impact on discharge has increased rapidly over the past years (figure 2).

These findings suggest that, in opposition to the conclusions made by Wang *et al* (2020), hydro-power is a key driver of the hydrological changes and that Chinese dams likely play considerable role in these changes: the impact of anthropogenic drivers in Chiang Saen is roughly one third of that in Stung Treng (figure 1), reflecting the influence of climatic and anthropogenic changes in the area between the two stations.

## 5. Changes in precipitation

Wang *et al* (2020) assess changes in annual precipitation, and use this as a predictor for their statistical model. We argue, based on our earlier statements, that changes in precipitation should also be assessed separately for dry (November–May) and wet (June–October) seasons. We carried out this assessment using TerraClimate data (Abatzoglou *et al* 2018; supplementary figure 2 (available online at [stacks.iop.org/ERL/16/058001/mmedia](https://stacks.iop.org/ERL/16/058001/mmedia))), and while our annual trend agrees well with Wang *et al* (2020), we found that most (63%) of the decreasing trend on Stung Treng drainage area occurred during the dry season, and would therefore have little impact on



**Figure 2.** Change in monthly mean discharge between modelled GLOFAS and observed discharge—indicating the impact of anthropogenic drivers such as hydropower operation—in 5 year periods (A) Chiang Saen and (B) Stung Treng; (C) historical increase in the number of dams and their total storage volume; and (D) map of the Mekong River Basin.

the peak inundation area. This should be taken into account when interpreting their findings, particularly considering the opposite signs in the detected trend for dry season precipitation (negative) and stream-flow (positive) (figures 1(A) and (C); supplementary figure 2).

## 6. Simplistic statistical modelling

Wang *et al* (2020) additionally present a Generalized Linear Model based on precipitation (P) in the High Correlation Zone (HCZ), number of dams in the basin, and evapotranspiration (ETP) within the entire basin as the predictors. However, the model is conceptually flawed, and cannot distinguish the influence of the Chinese cascade from other drivers.

Unfortunately we could not repeat the analysis due to little detail being given in the manuscript. A proper statistical model would need separate terms for (a) the Chinese dams and the LMB dams for both seasons (due to their different seasonal influence), (b) P and ETP products, validated for the Mekong Basin and covering the entire basin, and potentially separated for the different areas of interest (such as the HCZ, Tonle Sap, and the rest of the basin). The hydropower dams should be represented by their active storage volumes rather than their counts (see figure 2(C)). Further, the model should not forget to acknowledge the increasing water use within the basin, nor the water required to fill the reservoirs.

## 7. Conclusions

We show here that the analysis methods by Wang *et al* (2020) focusing on annual changes leads to misleading and even opposite findings compared to

an analysis where the nature of the flood pulse system is properly taken into account.

Our analysis indicates that anthropogenic changes, such as a dam operations, explain most of the significant reduction in annual high flow discharges observed along the Mekong River, while change in precipitation seems to play a smaller role. The annual high flows, in turn, were strongly correlated with the maximum inundation area of the TSL. Therefore, our findings suggest that dams are likely to play a strong role in altering the annual flood pulse of the lake, and thus its aquatic productivity.

While our statistical analysis is able to show the trends in discharge and potential impact of hydropower development in the basin, it cannot fully represent all the dynamics of such a complex system. We thus propose that further research should be conducted using the existing hydrological and hydrodynamic models—preferably an ensemble of both—to understand in more detail the specific impacts of both climatic and anthropogenic changes to the TSL flood pulse.

Despite our disagreement with the conclusions presented by Wang *et al* (2020), dam development in the Mekong is a pressing issue, and their work is a welcome addition to the discussion of its potential impacts. Successful management of the shared river can only be achieved when the impacts of its development are clearly understood.

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