Interactive comment on “The Kerala flood of 2018: combined impact of extreme rainfall and reservoir storage” by Vimal Mishra et al.

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Received and published: 26 October 2018

Note to the editor and authors: As part of an introductory course to the Master programme Earth Environment at Wageningen University, students get the assignment to review a scientific paper. Since several years, students have been reviewing papers that are in open online discussion for HESS or BGS, and they have been asked to submit their reports to the discussion in order to help the review process. While these reports are written in the form of official (invited) reviews, they were not requested for by the editor, and we leave it up to the editor and authors to use these reports to their advantage. While several students were often asked to review the same paper, this was not done with the aim to provide the authors with much extra work. We hope that these reports will positively contribute to the scientific discussion and to the quality of papers published in HESS. This report/review was supervised by dr. Ryan Teuling (teacher within the ITEE course at Wageningen University and also associated editor with HESS).

We really appreciate this amazing effort and learning experience. We consider all the comments positively and will address them in the revised version. Thanks to all the students and Dr. Teuling for this excellent review.

This study is aimed at finding the causes of the Kerala flood in August 2018. A gridded rainfall map of India was constructed for the analyses and data of major reservoirs in Kerala were gathered. Based on the available data reservoir characteristics, mass curves and depth-duration-frequency curves were constructed. Results showed unprecedented amounts of rainfall in catchments upstream of major reservoirs with return periods much larger than 500 years. It was also shown that most major reservoirs were almost at their full reservoir level at the start of the series of extreme rainfall events. It is concluded that both the high reservoir storage and extreme amounts of rainfall played a significant role in the large-scale flooding in Kerala. It is advised to improve forecasts of extreme rain at longer lead times to better manage reservoir operations. Research in this field has a high societal relevance since a better understanding of the causes of major floods, like in Kerala, can save future lives. A similar study, Sayama et al. (2012), also stresses the importance of this kind of analyses to better understand and prevent future floods. The study is also relevant since similar events are predicted to occur more often in India under the effect of global warming. However, in my opinion the authors did not conduct a sufficiently in depth study of this interesting case. Results are so extreme that validity of the data has to be questioned. Moreover, a proper discussion about these extreme outcomes is missing. Furthermore, some figures are missing or current figures need to be altered to improve the clarity of the paper. In spite of its high relevance, I would recommend that major revisions are necessary before the work can be published in HESS.

Thanks for the insightful suggestions. As suggested by the two reviewers, we have added more discussion and analysis in the revised version. Moreover, we have carefully checked the precipitation and other datasets used in the manuscript during the revision.

Major comments

(1) The paper concludes that rainfall in the catchments upstream of major reservoirs was unprecedented. It is stated that Idukki, Kakki and Periyar reservoir experienced 279, 700, and 420% surplus rainfall, respectively from their long-term mean between May 1 and August 21 in 2018. These values are so extreme that I highly doubt the correctness of the data. Moreover, the discussion section does not mention anything about these seemingly unrealistic results.

Thanks. We have evaluated the rainfall record again during the revision. The rainfall data is based on the gage stations of India Meteorological Department (IMD). We have collected observed station data to compare with the gridded data.

These conclusions are based on figures 3 and 4. Idukki, Kakki and Periyar reservoirs clearly stand out from the rest. In figure 3 the upstream catchments of Idukki, Kakki and Periyar reservoirs show cumulative rainfall amounts after three months that are already 2-3 times higher than the long-term average amount of rainfall for an entire year in these catchments. Furthermore, the cumulative amount of rainfall in these three catchments is far away from the grey area indicating the area within one standard deviation from the long-term mean. In figure 4 the upstream catchments of Idukki, Kakki and Periyar reservoirs show rainfall amounts during August 2018 for a duration of 15 days that are 2-3 times as high as the amount that would occur once every 500 years. Rainfall amounts depicted in figures 3 and 4 are so unprecedented that it is highly unlikely that these amounts actually occurred.

As stated above, we have carefully checked all the dataset and analysis in the revised manuscript to avoid any error.

Major alterations are necessary to sufficiently improve the discussion section and the results shown in figures 3 and 4. I would recommend to reconsider the data used to construct the figures. From the methods it is not clear to me whether a quality control has been conducted on the raw data. If not the case, I would strongly recommend to do one as this might eliminate outliers that cause the seemingly impossible results in figures 3 and 4. The quality control used in Yatagai et al. (2012) and Haylock et al. (2008) might be appropriate methods. Also, the discussion section should be expanded with a discussion about these extreme results.

Thanks. The two reviewers also suggested to improve the discussion. In the revised manuscript, we provide in-depth discussion on the simulated flow conditions, reservoir operations, the role of large-scale climate, and the role of extreme precipitation forecast. We used the standard gridded precipitation product from IMD, which has been evaluated against the other precipitation products (APHRODITE, Yatagai et al. (2012)). We have mentioned this in the revised manuscript.

(2) Major conclusions are solely based on data obtained from rain gauges in Kerala.

No information is given about the location of these gauges. Moreover, I am missing information about the size of the catchments upstream of the major reservoirs and the location of rain gauges in these catchments and their surrounding areas. Not including this information gives an incomplete picture of where the data comes from and what the data actually describes. Validation of the data could help in understanding how questionable results, like addressed in my previous point, can occur.

We provide more information on the number of rainfall gauge stations as well as the catchment area in the revised manuscript. We compare the gridded precipitation with the Global Precipitation Mission (GPM) as well as monthly station-based rainfall observations.

To improve the clarity of the paper I would first of all advise to include a map of all rain gauges in India, like is given in Pai et al. (2014a). In this map Kerala should be clearly delineated. By including this map readers of the paper will be able to see the density and distribution of rain gauges in India and Kerala. Furthermore, I think it is essential that separate maps of all reservoirs and their upstream catchments should be included. In this map the location of rain gauges in the catchment and its surroundings should be clearly indicated. Including these maps would contribute in understanding how the rainfall data of the catchments is obtained.

Thanks. We have used the rainfall station map in the supplemental section of the revised manuscript.

(3) In the paper variability is estimated using one standard deviation. One standard deviation indicates the variability in which 68% of the values will fall. This is meaningless since values outside this variability cannot be regarded as extreme.

Indicating variability with two standard deviations would be an improvement. 95% of all values will fall within a variability of two standard deviations, values outside this variability can now be regarded as extreme. This especially holds for figures 1a, 2 and 3. For example, extending the variability indicated by the grey area in figure 2 to two standard deviations would cause most values of 2018 to fall within this variability. Values that are outside this area can now be regarded as extreme, this would add to the strength and clarity of the figure.

Thanks. We have revised the plots using both one and two-standard deviations.

Specific comments

(1) Be consistent with writing down dates throughout the document.
Done

(2) Use “that” before “occurred” across the document like in p2 line 1, 9 and 32.
Done

(3) The statement made in p3 line 9 seems very extreme and I think these amounts of rainfall are highly unlikely to have occurred in large parts of Kerala. Also, when looking at the DDF curves this will result in gigantic return periods. Based on what is this statement based? I would remove this statement.
We have modified the statement, thanks.

(4) p2, line 1: missing “that” before “occurred”
Done

(5) p2, line 6: “Dottori et al. (2018)” instead of “Dottori et al., (2018)”
Done

(6) p2, line 6: “an” before “uneven”
Done

(7) p2, line 9: missing “that” before “occurred”
Done

(8) p2, line 19: missing “the” before “IMD”
Done

(9) p2, line 19: Cite Pai et al. (2014a) here since the dataset has been developed based on the methods described in this paper.
Done

(10) P2, line 22: The wrong citations are used here. Mishra et al. (2014) only cites a paper which makes this statement, Shah and Mishra (2015) does not make this statement at all. The only correct reference here should be Pai et al. (2014b).
Done

(11) P2, line 24 and 25: It is stated that “Gridded daily rainfall from IMD has been widely used in hydro-climatic studies” with five references to support this claim. However, all references are papers published by one of the authors. Add references which are not of one of the authors or do not state that it is “widely used”.
Thanks. Done

(12) p2, line 26 and 27: “curves” instead of “curve”
Done

(13) p2, line 31: “a” before “once”
Done

(14) p2, line 32: “The” before “return”
Done

(15) p3, line 6: “periods” instead of “period”
Done

(16) p3, line 6: “the” before “GEV”
Done

(17) p3, line 6: “a” before “Chi-square”
Done

(18) p3, line 6: replace “test, and we” by “test. We”
Done

(19) p3, line 7: remove the third “the”
Done

(20) p3, line 12: “IWRIS” instead of “WRIS”
Done

(21) p4, line 2 and 3: I would not use percentages, they are quite meaningless here in the way it is written down. Better use exact numbers or reformulate.
Done

(22) P4, line 7: “the” before “mean”
Done

(23) P4, line 8: remove last “,”
Done

(24) The statement made in p4 line 9 seems very extreme and I think these amounts of rainfall are highly unlikely to have occurred in large parts of Kerala. Also, when looking at the DDF curves this will result in gigantic return periods. Based on what is this statement based? I would remove this statement.
Done

(25) p4, line 16: the reservoir dataset from 2007-2017 is referred to as a long-term mean, I would not call 11 years of data a long-term dataset.
Done

(26) p4, line 14: Remove double spacing before “We”
Done

(27) p5, line 3: “respectively” before “279”
Done

(28) p5, line 23: “2018” before “in”
Done

(29) p5, line 28: “the” before “future”
Done

(30) p5, line 30: “1-5 day” instead of “1-5day”
Done

(31) p5, line 31: remove “the”
Done

(32) p6, line 8: “and” before second “land”
Done

(33) p6, line 12: “than” instead of “that”
Done

(34) p6, line 13: “periods” instead of “period”
Done

(35) p6, line 19: “of” before “extreme”
Done

(36) p6, line 26: “periods” instead of “period”
Done

(37) p6, line 28: remove “the”
Done

(38) p6, line 28: “periods” instead of “period”
Done

(39) p6, line 29: “were at” instead of “had”
Done

(40) p7, line 7: “time” before “can”
Done

(41) p7, line 7: “improving” before “reservoir”
Done

(42) Figure 1a: I would indicate the start of events on the 7th of August in the same way as in figure 3 with a thin line. Indication now looks like a weird dip in the data.
Done

(43) Figure 1 caption: state that the delineated part in India is Kerala.
Done

References

Haylock, M. R., Hofstra, N., Tank, A. K., Klok, E. J., Jones, P. D., New, M. (2008). A Eu-ropean daily high-resolution gridded data set of surface temperature and precipitation for 1950–2006. Journal of Geophysical Research: Atmospheres, 113(D20).

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Sayama, T., Ozawa, G., Kawakami, T., Nabesaka, S., Fukami, K. (2012). Rainfall–runoff–inundation analysis of the 2010 Pakistan flood in the Kabul River basin. Hydro-logical Sciences Journal, 57(2), 298-312.

Yatagai, A., Kamiguchi, K., Arakawa, O., Hamada, A., Yasutomi, N., Kitoh, A. (2012). APHRODITE: Constructing a long-term daily gridded precipitation dataset for Asia based

on a dense network of rain gauges. Bulletin of the American Meteorological Society, 93(9), 1401-1415.

Thanks. We have cited the relevant references.