

Thank you so much to the referee for the constructive comments. All the comments have been addressed and are detailed below.

General comments: The authors of this comment provide a critique which mainly centers on highlighting the “choice of inappropriate methodology (for a watershed which is actually gauged) and faulty assumptions by Penny et al. (2018) for analysing the watershed scale hydrological changes, generating misleading results and inferences”. These are very strong words and I have read the comment as well as the original paper by Penny et al. and the supplementary material carefully to evaluate the arguments brought to the table by this comment. I have to say that while I agree that it would have been good to compare the results of the distributed remote sensing based study with the observation well data that Bassi et al. refer to, there are also some arguments that seem to be based on misunderstandings. It would be important to take another close look at these arguments, check their validity and if possible show how the conclusions of Penny et al. are wrong before the comment is published. If in the end all that is left is the statement that Penny et al. should have made the effort of obtaining the observation well data I am also not sure if this really warrants the publication of this sort of comment. In this case a comment during the discussion phase of the manuscript by Penny et al. would have probably been more useful. In general I think the comment would profit from a slightly less confrontational tone, especially as some arguments seem to be based on misunderstandings. Actually showing how Penny et al. came to the wrong conclusions concerning the spatial patterns and their links to land use by doing a similar analysis based on the data provided by Bassi et al. would make this comment much stronger, but it is not clear if the coverage and spatial resolution as well as the length of the time series is sufficient to actually do this. The two stream gauges do not seem sufficient, but you could try to do this with the 75 observation wells.

**Response:** Thanks for the suggestions. On the data sets, we mentioned on the data availability with the Central agencies, State data centre has data for many more observations stations/sites (table 1) and as mentioned one has to visit them in-person to understand the status in Cauvery basin, in this case for Arkavathy watershed. Whereas Penny et al have used a methodology on the notion that data sets are not available and hence in all likelihood did not made any effort to consult the state data management agencies. Through this commentary, our aim is also to highlight the limitation of using a methodology (for a gauged catchment) which is more suitable for an ungauged-catchment. Onus, of comparing the results with the integral assessment based on officially available long term data was with Penny et al. which we have highlighted. On the tone and language used, the commentary has been edited several times and has been put forth for discussion only after incorporating suggested changes by the editor.

Specific comments:

p.1 l.24: what do you mean by “aggregate level changes”? Please rephrase or explain.

**Response:** In this case, it refers to the hydrological changes at the watershed scale. As suggested, we will elaborate this in the revised manuscript.

p.1 l.25: please clarify what spatial patterns you are referring to here. Do you mean the spatial patterns of long-term changes in runoff? Or the aggregate level changes? As I do not understand what you mean by that it would be good to phrase this more clearly.

**Response:** Actually, it is spatial patterns of long term changes in runoff and groundwater availability. We would make the statement clear in the revised manuscript

p.1.l.29: It is not uncommon to use methods for ungauged catchments on actually gauged catchments, either because the spatial and temporal resolution of the existing measurement data is insufficient for the purpose or because the data cannot be attained. In this case Penny et al. wanted to investigate the spatial pattern of runoff changes at a higher resolution than the official stream gauges provided.

**Response:** Sure, for this reason we have concluded the commentary by arguing that Penny et al should have compared the 'results obtained from the distributed assessment (appropriate for regions characterised by data scarcity) with the integral assessment based on officially available long term data, to draw appropriate inferences about the hydrological dynamics in Arkavathy watershed'. At least, an attempt should have been made to know the extent of official data availability.

p.2 l.8: "Often, existing resources with the official agencies to process and manage data properly are debated among the researchers" this sentence is unclear and needs to be rephrased.

**Response:** We simply mean it is 'often discussed among researchers in-person'. We will clarify this in the revised manuscript.

p.2 l.17: what does it mean, a "fully operational WDC"? What do they do exactly? I tried to find more information on the internet, but could not find their webpage or a webpage describing their services. It is mentioned here <https://www.karnataka.gov.in/karhp/Pages/Hydrology-Project-I.aspx>, but this doesn't provide details on how to obtain data. It would be helpful if you could provide more information here.

**Response:** 'WDC' refers to Water Data Centre (already mentioned in the previous line of the original manuscript) and 'fully operational' means that they are collecting, validating and processing (for further use) all the state hydrological data sets. For accessing the required data sets, one has to approach them formally. This has been already mentioned in detail in remarks column of Table 1 on page 7 of the original manuscript.

p.2. l.24/25: I do not think it is very helpful to provide the numbers of observation sites of the Cauvery river basin here, please only focus on the study area of Penny et al., the Arkavathy catchment.

**Response:** Since the whole debate is about the availability or non-availability of data, it is important to provide a larger picture in terms of data availability at the basin scale which can also be of use to other researchers who are interested in working on issues in Cauvery river basin.

p.2. l.29: "Therefore, it is not clear which data paucity the authors are referring to." These are quite harsh words, given the fact that Penny et al. wanted to study the spatial patterns of hydrological changes in the 4250km<sup>2</sup> Arkavathy catchment. This is difficult to do if, as you state, only 2 stream gauges exist. It is admirable that there are streamflow time series starting from 1934 for the 81000km<sup>2</sup> Cauvery River, but this is also not helping much with the issue of spatial patterns in the Arkavathy catchment. I agree that it might have been helpful for the study of Penny et al. to compare their results with the 75 time series of groundwater observation wells. However, you say that this data is only available from 1996 onwards, while the Penny et al. study is focusing on changes for a longer time period between 1973 to 2010. In Table 1 you state "The requested data sets have to be obtained physically on payment of processing charges". What does this mean, "obtained physically"? Please clarify. Maybe you can also provide the information on how much the processing charges are? Please also provide the length of the time series for the two gauging stations in the Arkavathy Catchment.

**Response:** There are reservoirs in the Arkavathy watershed as well. Nevertheless, we have already explained in detail in the original manuscript as well in the response to one of the previous comments regarding the data availability in the Arkavathy watershed and also on the fact that onus of comparing results (remote sensing based distributed assessment with integral assessment using official data sets) was with Penny et al.

Obtain physically means that one has to go there in-person and make a request formally. Payment charges will depend on the data sets requested which only the officials can tell.

As suggested, we will mention the time series of the data sets (available from 1979 onwards) for the two gauging stations in the revised manuscript.

p.2/3 l. 31-2: I do not find this statement in the text of Penny et al. They state that "There is little research that addresses the emergent effects and heterogeneity of human-driven hydrological change across the watershed scales at which management decisions must typically be made. The gap in scientific understanding at management relevant scales is strongly associated with a lack of data resolution at these scales, and..." which to me refers more to the spatial resolution that is necessary to capture the heterogeneity of the patterns. I would therefore suggest to rewrite or omit this sentence as it seems to be based on a misunderstanding.

**Response:** Thanks for the observation. As per our understanding, Penny et al. has argued that most of the research linking human drivers to hydrological responses considers administrative boundaries (Local, Regional, and National) rather than hydrological boundaries (watershed, sub-basin, and basin) as a unit of analysis. And that their study has considered the relevant hydrological scale. They are right that hydrological scales need to be considered but they should have acknowledged the contributions made by others. Thus the scale they are mentioning is for the hydrological unit (watershed, sub-basin or basin). This is what we have highlighted in lines 31-2 on page no. 2/3 in the original manuscript. Also, the argument has already been revised as per the suggestion of the editor.

p.3 l.3-6: do these studies look at the spatial patterns of hydrological response within the catchments at high resolution? Please add this information.

**Response:** As clarified above, the scale which Penny et al. is mentioning is for the hydrological unit (watershed, sub-basin, and basin). Accordingly, we have provided references in the original manuscript mentioning studies which have used empirical data to analyse the hydrological changes at the watershed and basin scale.

p.3 l.13: Penny et al. wanted to assess the spatial pattern of the hydrological changes, not simply the integral of hydrological changes. Please rephrase and reconsider your arguments under this aspect. I think this is where the main misunderstanding lies.

**Response:** As per our opinion, we do not have any misunderstanding. Perhaps, we should clarify again that our aim is to highlight the limitations of using the RS/GIS based methodology for the watershed which is gauged. Even in the conclusion, we have clearly mentioned that Penny et al. should have at least compared the results obtained through their distributed assessment by undertaking integral assessment using official data sets.

p.3 l.19: There are only 5 of these reservoirs, which is probably not enough to capture the pattern and variability the authors were after.

**Response:** That is why we mention that at least they should have compared the results. Penny et al has estimated changes in the surface areas of distributed tanks (using RS/GIS) and regarded them as

proxy for the balance of surface flows. In our opinion, such assessment are more uncertain than based on operational data (as mentioned in the original manuscript), depending on the precision of the satellite observations and on the degree to which the surface to volume ratio of the tanks is known. Such approach is useful for the ungauged areas. However, Arkavathy watershed is gauged. Therefore, we have mentioned in the original manuscript and state it again that at least they should have compared the results.

p.4 l.1.: This is discussed in Penny et al. p. 601

**Response:** We have checked again, Penny et al. have considered initial storage in all the tanks (which are spatially distributed) to be zero in spite of high inter-annual and spatial variability in rainfall (please refer lines 6-21 one page 4 of the original manuscript).

p.4. l.3: or happening at  $S=S_{max}$ , so variations in overflow do not produce variations in  $S$ . (as stated in Penny et al.). Please do not oversimplify when referencing the original study, this actually weakens your arguments.

**Response:** Thanks, we will revise the statement in the revised manuscript.

p.4. l. 12: You state “Third, the authors found that the variability in tank water extent due to precipitation across clusters spread throughout the Arkavathy watershed was similar (indicating no spatial variation in rainfall at the watershed scale) and for this they seem to have used rain gauging data for several locations (page 603 of Penny et al., 2018).” Penny et al. used rain gauge data from 62 locations and looked at trends from 1971-2010. The spatial variability of rainfall is resolved through the use of the large number of raingauges. They show their results of the precipitation analysis in the supplement and state that there is significant temporal variability but no temporal trend, so the same result that you confirm in Figure 2 and p.4 l. 12-19. If I have misunderstood your argument here, please rephrase and clarify.

**Response:** Our main argument is on the spatial variability of rainfall across the tank clusters which Penny et al has not considered. Apart from inter-annual variations, rainfall analysis presented in Figure 2 and discussed in the manuscript (lines 10-21, page 4 of the original manuscript) clearly show spatial variation in the rainfall in the upper, middle and lower parts of the watershed. Please further note that since the gridded rainfall data sets having high spatial resolution (0.25 X 0.25) is used, any variation has relevance even at the reservoir/tank scale (mainly between tanks located in different parts of the watershed).

p.5 l. 8: “The rising water level is likely to be in wells located downstream of urban centers: :” I don’t understand this statement. Which of the wells are located downstream of urban centers? This is something you know, not something you have to speculate on. Please clarify.

**Response:** This is to explain the groundwater behaviour using our local expert knowledge. Any future research study may explore on the surface-groundwater interactions in this watershed.

p.5 l. 10: The issue of wastewater increasing river water levels and leading to seepage into the aquifer: This seems to me to be an issue that is not really related to decreasing water storage due to irrigation with groundwater. And isn’t this mainly affecting wells and aquifers directly adjacent to the rivers downstream of the urban centers? This sounds like a more local effect. What about groundwater elsewhere?

**Response:** Peninsular India (where Arkavathy lies) is mostly underlain by hard rocks. In this region, wells go dry during summers (seasonal groundwater scarcity) but surface water bodies continue to receive wastewater from the city. We have provided data on amount of wastewater which flows from Bangalore city to one of the reservoirs in Arkavathy watershed (line 12-13, page 5). This leads to higher hydraulic gradient in the stream than in the groundwater (as wells are dry). We will further strengthen the paragraph by including discussion on the seasonal groundwater scarcity aspects and providing some references for the same.

Table 1: please only focus on the Arkavathy Catchment and the data available here, as this is the point of the comment. Providing measurement locations for the entire state of Karnataka is confusing and not really helping the discussion.

**Response:** We have provided the details of the data availability in the Arkavathy watershed in lines 26-29 on page 2 of the original manuscript. The idea of presenting this table (which is also suggested by the Editor) is to highlight the data availability with the state water data centre. One has to visit them to understand how many of these locations are within the Cauvery basin or more specifically in the Arkavathy watershed. We have mentioned this in the remarks column of the Table 1.

Figure 1: The figure is too small and not readable. I suggest focusing on the Arkavathy Catchment as this is where the study of Penny et al. took place. Also include the location of the 75 observation wells, possibly also indicating the length of the respective time series.

**Response:** This map is prepared by the Central Water Commission and hence we are unable to provide more details. But surely, it informs readers and other interested researchers on the hydrological observations sites in the basin. For similar reasons, we are unable to provide the location of wells in the watershed. Nevertheless, for groundwater, time series is mentioned in the caption of Figure 3, and for the stream gauges, we have already agreed to provide the time series.

Figure 3: Is this based on simply comparing the annual mean water levels in 1996 and 2015? It might be more interesting to supply the actual time series. Please also provide the locations of these wells in the map of the Arkavathy Catchment (revised Figure 1). It would also be more useful to actually show the entire data set of groundwater time series of all 75 observations wells. That would be much more convincing than showing just a selected few.

**Response:** Figure 3 is based on comparing the observed (by CGWB) pre monsoon water level (to account for draft in a given year) data of each well. It is not the average. We have used only those wells for which data was available with us and these wells have been spread across Arkavathy watershed. Thus, spatial variation is captured, we can provide the lat-long of the wells in the revised manuscript. For data on all the 75 observation wells, one has to approach CGWB or Karnataka State Water Data Centre which we would not like to do for the commentary.