Revision notes for "Attribution of climate change and human activities to streamflow variations with a posterior distribution of hydrological simulations"

(hess-2021-528)

We would like to thank the editors and reviewers for the constructive feedback. We appreciate the valuable and thoughtful comments, which have certainly helped to improve the presentation and quality of our manuscript. We have updated our paper according to your comments and the detailed responses to the comments are described as follows.

Answers to the reviewers in blue.
Modifications of the manuscript in orange.

To Reviewer #2:

General Comments:

The authors evaluated the attribution of climate change and human activities to streamflow variations with a posterior distribution of hydrological simulations. The contribution distribution has been evaluated in many hydrologic fields using the different methods, however, the posterior distribution has been rarely considered. The author tried to provide a solution to evaluate the attribution of climate change and human activates considering the simulation uncertainty.

Responses to comments one by one:

1. Line 65-70, the second typed of method seems to be no difference with the third type of method. For example, I can understand that controlling human activities should be to change the climate factor like the second method simulating multiple scenarios by changing one impact factor. What is the nature difference for the two methods, please describe more clearly.

Response: Thanks very much for your comments. Based on your suggestion, we have re-summarized and classified research methods to quantify the contribution rate of climate change and human activities to streamflow change. In the revised manuscript, we re-describe the difference between these three types of methods, and the modified content is as follows:

Line 57-60, Page 2 in the revised manuscript

In general, the commonly used methods of attribution analysis can be divided into the following three categories: 1) conceptual methods, such as the Budyko framework (Li et al., 2007; Liu et al., 2017); 2) hydrological simulation methods (Liu et al., 2019); and 3) analytical methods, such as the climate elasticity method (Liang et al., 2013).

Line 71-74, Page 3 in the revised manuscript

The third type of method is mostly based on numerical calculation, taking the climate elasticity method as an example (Liang et al., 2013), this method introduces the concept of climate elasticity to define the quantitative relationship between changes in streamflow and climatic variables (precipitation, evapotranspiration, etc.), and the CR of HAs to streamflow changes can be obtained by subtracting the CR of climate variables.

References:

Li, L. J., Zhang, L., Wang, H., Wang, J., Yang, J. W., Jiang, D. J., Li, J. Y., and Qin, D. Y.: Assessing the impact of climate variability and human activities on streamflow from the Wuding River basin in China, Hydrological Processes: An International Journal, 21, 3485-3491, 10.1002/hyp.6485, 2007.

Liang, K., Liu, C., Liu, X., and Song, X.: Impacts of climate variability and human activity on streamflow decrease in a sediment concentrated region in the Middle Yellow River, Stochastic environmental research and risk assessment, 27, 1741-1749, 2013.

Liu, J., Zhang, Q., Singh, V. P., and Shi, P.: Contribution of multiple climatic variables and human activities to streamflow changes across China, J Hydrol, 545, 145-162, 10.1016/j.jhydrol.2016.12.016, 2017.

Liu, J., Zhou, Z., Yan, Z., Gong, J., Jia, Y., Xu, C.-Y., and Wang, H.: A new approach to separating the impacts of climate change and multiple human activities on water cycle processes based on a distributed hydrological model, J Hydrol, 578, 124096, 10.1016/j.jhydrol.2019.124096, 2019.

2. Line 91-94, as you stated, Farsi and Mahiouri (2019) has also analyzed the uncertainty of hydrological simulations in the process of quantifying the CR of CC and HAs to streamflow changes, however, you thought they only constructed the posterior distribution of the contribution rates of climate change and human activities, and did not specify the accurate contribution rates. I don't think so, Farsi have provided the PDF of contribution rates which can tell high-probability contribution rated clearly. Therefore, what is the innovation for this study differing from the previous studies, not averaging the contribution rates with high-probability NSE.

Response: Thank you very much for your comments. We strongly agree with you that Farsi and Mahiouri (2019) have indeed presented a PDF of the contribution rate in their study. However, we believe that our current research has made some expansions on the basis of their research, and the main innovations or expansions are as follows:

1) Farsi and Mahiouri (2019) constructed a PDF of the contribution rate in their study, and compared it with the optimal simulation results of the hydrological model to prove that the results with the highest frequency fully consider the

uncertainty of hydrological simulation. However, the research results presented in Section 5.1 of our study show that the parameter combination with the best simulation performance may have a large difference in the calculated contribution rate from the actual situation.

2) In addition to using the Budyko method to verify the calculation results considering the uncertainty of hydrological simulation, our research also constructed a rough estimation method for quantifying the contribution rate of climate change and human activities to streamflow change in areas where reservoir construction is more active, which can provide method reference for other researchers.
3) According to your suggestion, we added the analysis of parameter uncertainty in the discussion section, and calculated the frame calculation results after excluding unreasonable parameters. This is also an extension of the Farsi and Mahiouri's research to some extent, and it can provide a method reference for the research area with true values of the relevant parameters of the hydrological model.

References:

Farsi, N. and Mahjouri, N.: Evaluating the contribution of the climate change and human activities to runoff change under uncertainty, J Hydrol, 574, 872-891, 10.1016/j.jhydrol.2019.04.028, 2019.

3. Line 344-345. The plant-avaiable water coefficient is set to 0.5, why? It is just to match the result of your proposed method? In addition, the contribution method should be not your finding, is it?

Response: Thank you very much for your comments. In Zhang's research (Zhang, et al., 2001), it provides the ratio of mean annual evapotranspiration to rainfall as a function of the index of dryness for different value of plant-available water coefficient (Figure 1). For our study area (Lancang River Basin), the multi-year average E_0/P and ET/P values from 1961 to 2015 are 0.55 and 0.96, respectively. Therefore, according to the selection method shown in Figure 1, we set the ω value to 0.5 in this study.

In the revised manuscript, we have added a description of how the value of ω is chosen as follows:

Line 354-356, Page 15 in the revised manuscript

According to the method for selecting the value of ω provided in Zhang's research (Zhang et al., 2001), and based on the multi-year average AE/P (0.55) and PET/P (0.96) values in the LR Basin, this study set the value of ω to 0.5.

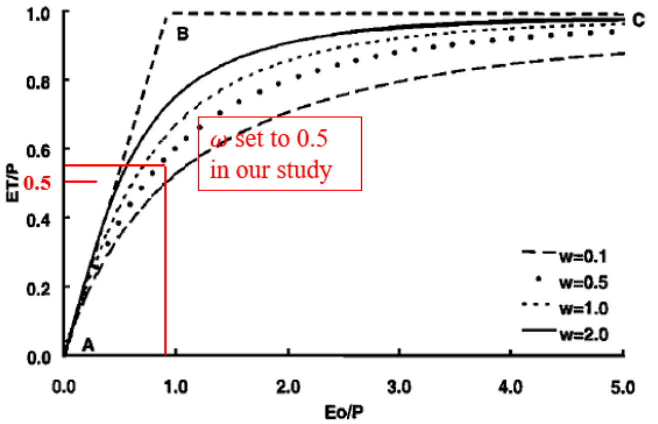

Figure 1. Ratio of mean annual evapotranspiration to rainfall as a function of the index of dryness (E_0/P) for different values of plant-available water coefficient (w).

Figure 1 How to choose ω-values that apply to different study areas. (Notation: E_0 = potential evapotranspiration, ET = actual evapotranspiration)

References:

Zhang, L., Dawes, W., and Walker, G.: Response of mean annual evapotranspiration to vegetation changes at catchment scale, Water resources research, 37, 701-708, 10.1029/2000WR900325, 2001.

4. L440, the sensitivity analysis method is not describe clearly, SUFI-2 is a optimal method, and how it conduct parameter sensitivity analysis, what is its relation with Latin hypercube sampling?

Response: Thank you very much for your useful comments. As you stated, SUFI-2 is a parameter optimization method and cannot do parameter sensitivity analysis. Therefore, in the revised manuscript, we have revised this part of the content, and the added content is as follows:

Line 456-460, Page 19-20 in the revised manuscript

As descripted in Section 3.4.2, the sensitivity of 22 selected parameters was evaluated using the SWAT-CUP software (Abbaspour et al., 2007), and this software integrates the global sensitivity analysis method and the parameter optimization methods (such as SUFI-2). The SWAT-CUP can perform a combined optimization and uncertainty analysis using a global search procedure and can deal with a large number of parameters through Latin hypercube sampling.

References:

Abbaspour, K. C., Yang, J., Maximov, I., Siber, R., Bogner, K., Mieleitner, J., Zobrist, J., and Srinivasan, R.: Modelling hydrology and water quality in the pre-alpine/alpine Thur watershed using SWAT, J Hydrol, 333, 413-430, 10.1016/j.jhydrol.2006.09.014, 2007.

5. About "equifinality for different parameters" of hydrological simulations. The author selected some experiments with high NSE larger than 0.75 to construct the posterior histogram frequency distribution (PHD) of the contribution rate of climate change and human activities to streamflow changes, and then quantify the contribution rates with higher probability. I think it does not solve the "equifinality for different parameters". The simulations with higher probability still exist the "equifinality for different parameters". To exclude it, the uncertainty (pdf) of parameter should be analyzed to screen out abnormal parameter values. After that, the contribution rates with higher probability are really results excluding the "equifinality for different parameters". These suggestion may be added into the discussion section in revised manuscript.

Response: Thanks very much for your comments. We acknowledge that the current methods used in our study have not solved the problem of "equifinality for different parameters" in hydrological simulations, because simulations with higher probability still has unreasonable parameter combinations. Therefore, following your suggestion, in the revised manuscript, we have made the following modifications:

1) In this study, we selected 9 parameters with higher sensitivity among 22 parameters to construct a computational framework to quantify the contribution rate of climate change and human activities to streamflow change. We first analyzed the uncertainty of 9 parameters with higher sensitivity in 575 simulation results (NSE greater than 0.75), and the results are shown in Table 1. From Table 1, we can see that although we have selected a combination of parameters with better simulation performance according to the NSE value (greater than 0.75), these parameters still have great uncertainty (with large 50CI and 90CI values). Among them, the parameter CH_K2, the second sensitive parameter, has the largest uncertainty. For the parameters related to snowmelt runoff (SFTMP and SMTMP), although it has a relatively reasonable median value (-5.39 ℃ and 0.99 ℃, respectively), however, there are still values in the range of 50CI and 90CI that are not in line with their physical meanings. This also means that although the calculation framework proposed in this study can effectively reduce the influence of the uncertainty of hydrological simulation, there are still unreasonable parameter combinations in the calculation process.

Table 1 Uncertainty ranges for 9 highly sensitive parameters

Parameter	V__ ALPHA_BNK	V__ CH_K2	V__ SOL_BD	V__ GW_REVAP	V__ SFTMP	R__ CN2	R__ SOL_K	V__ SMTMP	V__ ALPHA_BF
median	0.69	213.12	1.85	0.08	-5.39	0.02	0.11	0.99	0.51
50CI	(0.53,0.85)	(103.6,352.5)	(1.48,2.17)	(0.04,0.13)	(-11.9,1.3)	(-0.09,0.12)	(-0.3,0.48)	(-9.7,11.5)	(0.25,0.75)
95CI	(0.22,0.98)	(14.2,488.0)	(0.96,2.47)	(0.01,0.19)	(-19.4,13.6)	(-0.19,0.19)	(-0.7,0.76)	(-19,19.1)	(0.03,0.97)

(Notation: 50CI (confidence interval) is expressed by the upper (75%) and lower (25%) bounds of the posterior parameter values among the 575 simulation results; 95CI (confidence interval) is expressed by the upper (97.5%) and lower (2.5%) bounds of the posterior parameter values among the 575 simulation results)

2) Based on your suggestion and the parameter uncertainty analysis in 1).

According to the physical meanings of the 9 parameters with high sensitivity, we selected the values of snowmelt runoff-related parameters (SFTMP and SMTMP) with clear physical meanings as a reference for further research, because we could not obtain the actual values of the other 7 parameters in the Lancang River Basin. After fully collecting the recommendations of relevant references for the value ranges of the two parameters (Abbaspour et al., 2007; Arnold et al., 1998; Yang et al., 2017), this study excluded the parameter combinations outside the recommended value ranges of the two parameters (-5℃ ≤ SFTMP and SMTMP ≤ 5 ℃), and finally obtained 55 parameter combinations. According to the selected 55 model simulation results, the contribution rate of climate change and human activities to streamflow change in the Lancang River Basin considering the uncertainty of hydrological simulation was calculated. The results are shown in Figure 2. It can be seen from Figure 2 that among the 55 selected simulation results, 16 calculation results (the most number) indicate that the contribution rate of climate change to the reduction of streamflow in the Lancang River Basin is 45-50% (with an average CR of 47.1%). This calculation result is consistent with the results presented in Fig. 10 which derived from the novel framework proposed in our study. They both show that the contribution rate of human activities to the reduction of streamflow in the Lancang River basin is greater than that of climate change, and the error between the two calculation results is about 4.5%.

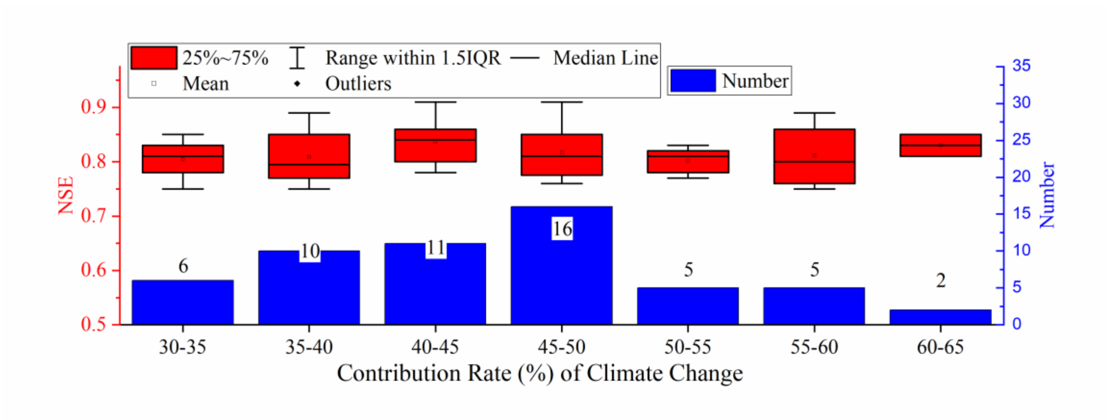

Figure 2 Histogram of the number of simulations (exclude parameter combinations with unreasonable values) of the CR (with 5% steps) of climate change to streamflow reduction in the LR Basin at the annual scale and corresponding Nash-Sutcliffe Efficiency box plots.

In general, according to the above research results, it can be seen that the computational framework based on statistical methods used in this study can effectively reduce the impact of uncertainty in hydrological simulations. The reviewer's suggestion in 2) can also provide a method reference for other similar regions, especially for some research areas where hydrological model parameters can be obtained.

Based on the above research results, we have added the following content in the Discussion 5.1 section of the revised manuscript:

Line 672-691, Page 30-31 in the revised manuscript

In this study, 575 parameter combinations with good simulation results (NSE greater than 0.75) were selected, with a step size of 5%, it is proposed to reduce the influence of hydrological modeling uncertainty on the quantitative results by constructing the posterior histogram distribution of the CR of CC and HAs to watershed streamflow change. However, it is undeniable that there are still unreasonable parameter combinations in the simulation results with high probability (167 times). For the LR basin, it is almost impossible to obtain the measured values of all 9 parameters with high sensitivity (Table 3). Therefore, in order to further explore the possible influence of unreasonable parameter values on the quantitative results, we selected two parameters related to snowmelt streamflow (SMTMP and SFTMP) to exclude unreasonable parameter combinations. According to the parameter value ranges recommended by Abbaspour et al. (2007) and other related references (Arnold et al., 2012a; Yang et al., 2017), in this study, the reasonable value range of these two parameters is set to -5 to 5 ℃. After excluding parameter combinations outside this value range, we obtained 55 simulation results with relatively reasonable parameter values, and the quantization results obtained from this calculation are shown in Fig. 15. It can be seen from Fig. 15 that after excluding unreasonable parameter combinations, the calculated CR of CC in the LR Basin to the reduction of streamflow is 45-50% (with an average CR of 47.1%), and this result is consistent with the results presented in Fig. 10 which derived from the novel framework proposed in our study. At the same time, it is also proved that although the calculation framework proposed in this study may contain unreasonable parameter combinations in obtaining the simulation results with the highest frequency, the calculation results are still highly accurate. In addition, for the research area where the measured values of related parameters can be obtained, the rationality and authenticity of the parameter values should be fully considered while selecting the parameter combination with higher NSE.

References:

Abbaspour, K. C., Yang, J., Maximov, I., Siber, R., Bogner, K., Mieleitner, J., Zobrist, J., and Srinivasan, R.: Modelling hydrology and water quality in the pre-alpine/alpine Thur watershed using SWAT, J Hydrol, 333, 413-430, 10.1016/j.jhydrol.2006.09.014, 2007.

Arnold, J. G., Srinivasan, R., Muttiah, R. S., and Williams, J. R.: Large area hydrologic modeling and assessment part I: model development, JAWRA Journal of the American Water Resources Association, 34, 73-89, 10.1111/j.1752-1688.1998.tb05961.x, 1998.

Yang, L., Feng, Q., Yin, Z., Wen, X., Si, J., Li, C., and Deo, R. C.: Identifying separate impacts of climate and land use/cover change on hydrological processes in upper stream of Heihe River, Northwest China, Hydrological Processes, 31, 1100-1112, 10.1002/hyp.11098, 2017.