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Discussions

Interactive comment on "Quantifying streamflow and active groundwater storage in response to climate warming in an alpine catchment, upper Lhasa River" *by* Lu Lin et al.

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Interactive comment on "Quantifying streamïňĆow and active groundwater storage in response to climate warming in an alpine catchment, upper Lhasa River" by Lu Lin et al. Anonymous Referee #1 Received and published: 6 July 2019

This paper presents the temperature, precipitation and stream variation in the Yangbajain catchment. Interestingly, the estimate the base ïňĆow and connect the baseïňĆow variation with the climate change. This is important for the local water resources management and well as for the global groundwater-climate change research. But it should be accepted after a minor revision. Response: Many thanks for the positive comments and suggestions. We have addressed the reviewer's concerns and suggestions carefully. In the following, we provide point-by-point response to each reviewer comment (blue texts are our responses, while black texts are original comments).

My major comments are: 1. The accuracy of base ïňĆow and groundwater storage estimation. As I pointed out in the speciïňĄc comment, the authors should provide more evidences to show the estimated groundwater storage are correct. Response: Yes, we agree that the results need to be verified by more evidences. However, as we know, at catchment scale, especially in Alpine regions, there are few direct methods to measure water storage at catchment scales, and direct observations of permafrost are even difficult to perform (Lyon et al., 2010; Creutzfeldt et al., 2014; Rogger et al., 2017; Patnaik et al., 2018). Several alternatively indirect methods have been proposed to try to validate the estimation from recession analysis. Vannier et al. (2014) compared the recession analysis based estimation of groundwater storage capacity with the method that estimates storage capacity by multiplying the soil thickness and specific yield. Birkel et al. (2011) used a tracer-constrained process-based conceptual model to validate storage dynamic estimated from the recession analysis based method. These indirect methods are considerable at small catchment with humid climate. Although superconducting gravimetry can measure the storage dynamic directly (Creutzfeldt et al., 2014), it is costly and only available at specific location. Instead, the GRACE data were used to verify our estimations in this study. In addition, we know that groundwater level is rising through recent field investigations. The increases of surface water and shallow groundwater are changing the land cover and NDVI (Figure 1) is rising accordingly in recent years. All these provide evidences to the estimated rising groundwater storage. In fact, not only in the study area but in the whole TP as well as surrounding regions, surface water and groundwater storage are increasing due to climate warming, and hence vegetation conditions are improved (Zhang et al., 2018; Khadka et al., 2018).

2. The explanation on the glacier loss should be deleted. Please see the speciïňĄc

comment (Line 408-413). Response: it has been revised accordingly.

3. The schematic model (Figure 3). (1) The glacier thickness should increase with the altitude; (2) 'Unconsolidated material' changes 'Unconsolidated soil layer'; (3) Take care of the width of the arrows. Response: Thank you very much for your suggestions. According to your suggestions and those of the second reviewer, we have made corresponding modifications by considering local real situations in the study region, as shown in figure 2.

SpeciïňĄc comments: Line 115&117 What is the method difference between Lyon et al. (2009) and Kirchner et al. (2009)? And what is the latest advance of the recession analysis? Please clarify. Response: Lyon et al. (2009) method is based on the recession flow analysis developed on the basis of hydraulic groundwater theory by Brutsaert and Nieber (1977) and Brutsaert (2008). However, Kirchner (2009) derived a nonlinear first-order dynamical equations by the conservation-of-mass theory for simulate the streamflow hydrograph from precipitation and evapotranspiration. The power law recession relationship which is used to characterize catchments based on nonlinear reservoir model or a Boussinesq representation of subsurface flow is only a special case in Kirchner's study. In hydrology, the storage-discharge relationship is a fundamental catchment property and can provide a functional form for recession analysis (Lyon et al., 2010; Creutzfeldt et al., 2014). However, to date, there are few direct methods to measure water storage at catchment scales, let alone to measure permafrost change in Alpine regions (e.g., the Qinghai-Tibet Plateau). Thus explicit storage-discharge relationship still remains unknown to us. Creutzfeldt et al. (2014) adopted direct measurements of terrestrial water storage dynamics by means of superconducting gravimetry in a small headwater catchment to derive empirical storage-discharge relationships. As direct measurement remains a major challenge, Birkel et al. (2015) and Soulsby et al. (2015) use a tracer-aided hydrological model to characterize catchment storage. Though many new methods (e.g., tracer-aided model) are proposed, to date, the classical technique of recession flow analysis according to recession flow or flow during noâĂŘrain periods sustained by basin storage (S) is still widely used to provide important information on storage–discharge relationship of the basin (Patnaik et al., 2018). This is because many methods are limited by observations. For instance, in many catchments, especially in Alpine regions, hydrological observations are sparse and direct observations of permafrost are difficult to perform. Most importantly, the recession flow analysis is based on widely available hydrologic data (i.e., streamflow data). As an important component of hydrograph, the nonlinear properties and inconsistency of recession segments among events are emphasized to give better parameterization of recession process through both hydrograph analysis and analytical and numerical simulation (Bogaart et al., 2013; Dralle et al., 2015, 2017; Gao et al., 2017; Hogarth et al., 2014; Roques et al., 2017; Sawaske and Freyberg 2014; Stoelzle et al., 2013). Recession analysis now works as an effective tool to explore catchment-scale physical attributes, such as catchment-scale hydrogeological parameters (saturated hydraulic conductivity, aquifer thickness), active river network dynamic, and storage capacity (Biswal and Kumar, 2014; Pauritsch et al., 2015; Shaw et al., 2016; Troch et al., 2013, Vannier, 2014). The catchment hydrological functions are also revealed through recession analysis. Hydrologic fluxes (actual evaporation, different streamflow components) and state-variables (like storage dynamic) can be estimated from recession analysis (Creutzfeldt et al., 2014; Shaw and Riha, 2012; Szilagyi et al., 2007;). A simple dynamic model can be even developed based recession analysis (Kirchner, 2009; Rusjan and Mikoš, 2015; Teuling et al., 2010). Besides, the streamflow recession patterns are used to unravel the co-evolution of landscape (Bogaart et al., 2016) and also the impact of climate change on permafrost degradation (Lyon et al., 2009; Ploum et al., 2019).

Line 163, 164&168. Please describe the number clearly on the period as well as the hydrologic station. Response: it has been revised accordingly. The air temperature of the Yangbajain Catchment is the areal average value over the whole catchment, which is calculated by the method of meteorological data extrapolation by Prasch et al. (2013). The precipitation and streamflow is the statistical values at the Yangbajain station.

Line 169-171 How do you get the number of 63% from Fig. 2. And I do not think you can get this number easily only with the data of temperature, precipitation amount and runoff. Response: it is a little bit puzzling. Here we mean the runoff volume in summer account for 63% of the annual streamflow volume and it has been revised accordingly.

Line286-288 The higher grade relational grade is found at the annual scale, how can you say the air temperature also acts a primary role for the base ïňĆow? Response: According to the trend analysis of hydro-meteorological factors (e.g., precipitation, Air temperature, etc), we found that baseflow as well as streamflow are both increasing. Through gray relational analysis, we aim to identify the major climatic factors for the increasing streamflow. The result shows that the air temperature compared with precipitation has the higher gray relational grade at annual scale (Table 2). This indicates that the air temperature instead of precipitation acts as a primary factor for the increased streamflow as well as the baseflow. The continuous warming has led to glacier loss and permafrost degradation that contribute to the increasing of streamflow.

Line 339-344 I suggest to shift these sentences above the lines 335-339. Before discussing the trend of the groundwater storage, you should ïňĄrstly explain the obtained results of groundwater storage are reasonable. I also ask the authors to give more explanation on their obtained groundwater storage, because it does seem consistent between the Grace data and your data. Could the authors give more evidences of the monitored groundwater level? Response: these sentences have been shifted accordingly. As you know in the harsh Yangbajain catchment there are no monitored groundwater wells observed by either official departments or scientific community. At this stage, we have to seek to public data (e.g., GRACE data) for verifications of our estimations. In addition, we know that groundwater level is rising through recent field investigations. The increases of surface water and shallow groundwater are changing the land cover and NDVI (Figure 1) is rising accordingly in recent years. All these provide evidences to the estimated rising groundwater storage. In fact, in the whole TP as well as surrounding regions, surface water and groundwater storage are increasing due to climate warming, and hence vegetation conditions are improved (Zhang et al., 2018; Khadka et al., 2018)

Line 356-370 I understand the authors try to draw the conclusion 'the increased streamïňĆow is mainly fed by the accelerated glacier retreat rather than frozen ground degradation' through the comparison between four catchments. This is something kind of 'circumstantial evidence'. Could you explain why the frozen ground degradation does not increase the streamïňĆow? Response: Yes, we agree that it is some kind of circumstantial evidence. The frozen ground degradation also contributes to the increasing of streamflow. However, through parallel comparison of different sub-basins (Table 3), we can conclude that the contribution of glacier retreat is much larger than frozen ground degradation. While the mostly significant effects of frozen ground degradation on runoff is that it can increase groundwater storage space and change the behavior of storage-discharge in the catchment. Similar results can be found in many other studies, e.g., Xu et al. (2019), Khadka et al. (2018) and Walvoord and Striegl (2007). For example, Walvoord and Striegl (2007) found that permafrost thawing in an arctic basin has resulted in a general upwards trend in groundwater contribution to streamflow of 0.7-0.9%/yr, however, with no pervasive change in total annual runoff.

Line 408-413. This is quite arbitrary. Although the estimation of glacier loss is reasonable, the loss can be explained in many ways. For example, it could be delivered through the different pathways of shallow aquifer; and it could be exchanged with the aquifers outside the studied region. Sure, it may also inïňĄltrate into the deep fault. But all of these hypotheses need evidences. If you take the one of deep circulation, you should describe clearly the hydrogeologic features of the fault. Is it conductive or not? What is the depth of it? What is the groundwater ïňĆow direction inside it? Could you provide the hydrogeologic section map here? If the authors could not provide the discussion above, I suggest the authors to delete this paragraph and leave the glacier loss as an open discussion question here. Response: Yes, we agree with the reviewer's comments and it has been deleted.

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Please also note the supplement to this comment:
https://www.hydrol-earth-syst-sci-discuss.net/hess-2019-302/hess-2019-302-AC2-supplement.pdf

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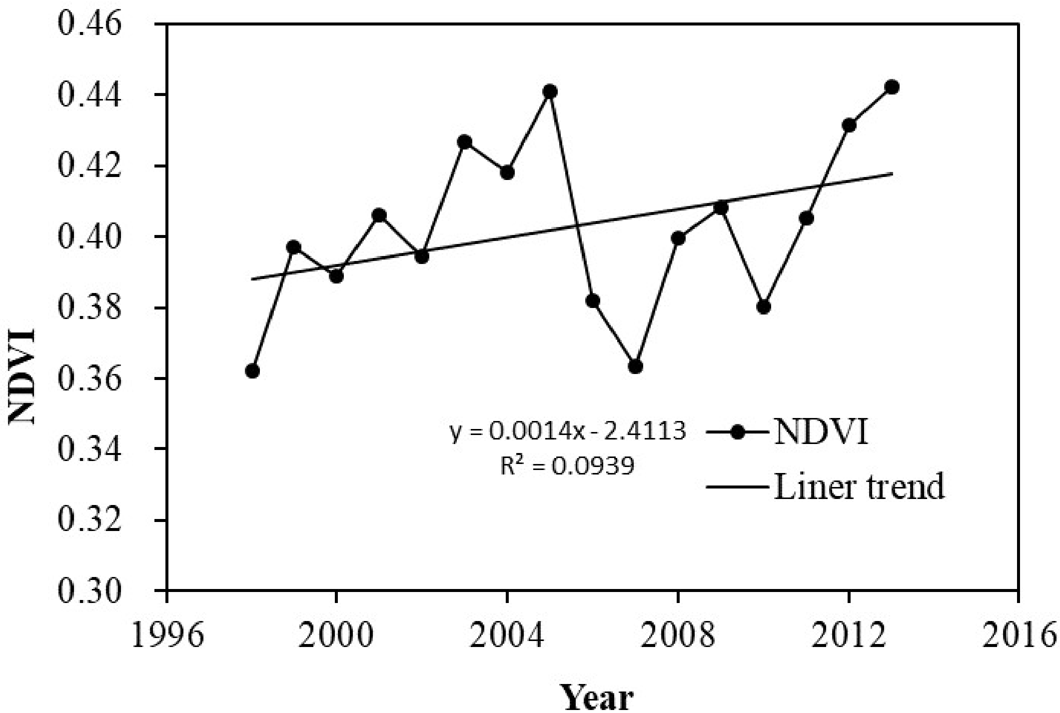

Fig. 1.

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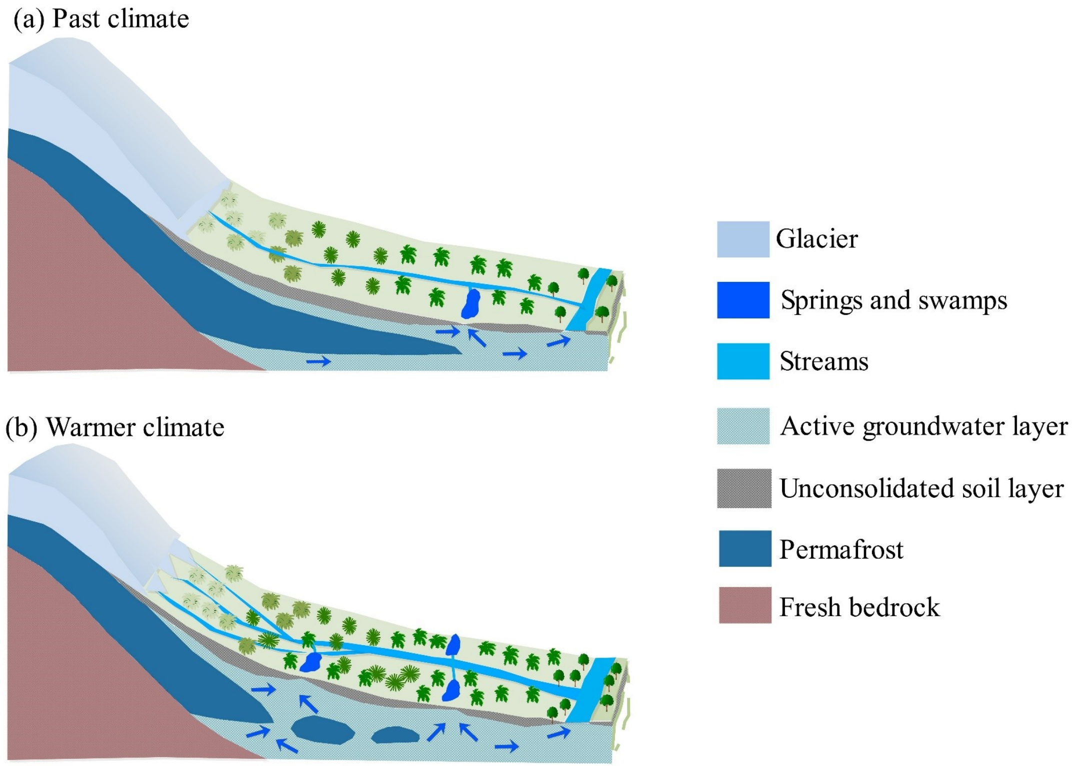

Fig. 2.

Interactive comment

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