Replies to Referee #2

Dear Anonymous Referee #2,

Re: Manuscript entitled "Exploring the Potential Processes Controls for Changes of Precipitation-Runoff Relationships in Non-stationary Environments".

We greatly appreciate the Referee's comments. All suggestions are helpful to improve this manuscript. We have carefully studied, considered and responded to all comments point-by-point as follows. For clarity, all comments are given in black and responses are given in the blue text. All the comments and suggestions have been replied to below and will be addressed in the revision.

Yours sincerely,

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To address the issue that present models assuming stationary conditions may result in incorrect streamflow forecasts, this study established a Driving index for changes in Precipitation-Runoff Relationships (DPRR). It provides possible process explanations for variations in precipitation-runoff relationships (PRR) using quantitative findings from inserting candidate driving factors into a holistic conceptual model. The study investigated the effects of climate forcing, groundwater, vegetation dynamics, and human activities on PRR in a non-stationary environment. This paper is important for hydrology since it provides a new perspective on hydrological processes and theoretical support for the building of long-term hydrological models. The manuscript is well presented. Furthermore, the authors responded adequately to the prior two reviewers' suggestions, resulting in improvements to the paper's scientific value and study technique.

The study chooses ISR, NTL, and POP as factors to represent the impact of human activities on precipitation-runoff connections, and one factor each to investigate climate, groundwater, and vegetation dynamics. ISR, NTL, and POP are all intimately related in the context of urbanization. High ISR is typically associated with a greater population, higher levels of urbanization, and an increase in NTL. These three aspects interact; for example, population growth stimulates infrastructure expansion, which improves ISR and NTL. The writers are asked to explain why they chose these three elements to indicate human impact. Furthermore, ISR and NTL data are mostly acquired from remote sensing products, whereas POP data are primarily gathered through administrative planning, resulting in limited thorough observations of these data, particularly for distant historical periods. There are discrepancies between the timeframes of these data and other databases. The writers should explain the significance of these inconsistencies.

Reply: We greatly appreciate the positive evaluation for this study. The influence of anthropogenic factors on the Precipitation-Runoff Relationship (PRR) is complex and multifaceted. Although ISR, NTL, and POP are closely related, their impacts on PRR vary significantly. Impervious surfaces, composed of man-made structures that impede natural water infiltration, are a key component of urban residential areas (Gong et al., 2020). The high ISR in urbanized regions affects surface energy and water balance, influencing extreme precipitation and flooding events (Lu et al., 2019). NTL products offer comprehensive insights into the impact of human presence and economic development on water resources (Ceola et al., 2019). Higher POP typically leads to increased urbanization, resulting in more impervious surfaces such as buildings and roads, along with heightened water demand (Fang and Jawitz, 2019). These three factors were selected to comprehensively explore the influence of anthropogenic factors on PRR.

Compared to traditional hydrological models, the Driving index for changes in Precipitation-Runoff Relationships (DPRR) requires less data and provides a straightforward and effective technique to identify potential driving factors affecting PRR. The proposed DPRR index quantifies driving levels and enables comparative analysis between different driving factors with varying data lengths and across diverse types of basins. In addition to ISR, NTL, and POP, this study further investigates anthropogenic influences over the study period, particularly reservoirs and their associated large-scale irrigation zones, to better understand the driving mechanisms of anthropogenic factors.

The relevant content is presented in Section S5 of the *Supporting Information* as well as Sections 2.2 and 3.2 of the manuscript.

Within a given period, the driving level of DPRR represents the level of influence exerted by a specific factor on the correlation between precipitation and runoff during the period, while the driving direction of DPRR indicates whether a specific factor has positive or negative effects on the PRR during the period. Does this indicate that factors with a positive driving effect would increase runoff? Furthermore, because the results of DPRR and D-DPRR change over different durations, the influence of numerous factors on PRR remains unknown. In the version, vertical variations in the violin plot reflect the uncertainty in DPRR results. However, where is the uncertainty in D-DPRR data reflected?

Reply: Thank you for the Referee's reminding. During a given period, the driving direction of the DPRR indicates the influence of a specific factor on PRR. However, it is essential to note that DPRR is constructed based on DCCA and DPCCA and represents a statistical approach. The DPRR index captures only the driving level and direction of factors influencing PRR changes and does not directly reflect specific hydrological processes or water fluxes within the hydrological cycle. Therefore, a factor with a positive driving influence does not imply an increase in runoff.

DPRR elucidates potential driving mechanisms affecting PRR at various timescales, enhancing our understanding of hydrological responses to climatic forcing and human activities across different temporal scales. The dispersion of the DPRR index along the vertical axis of violin plots reflects its uncertainty across timescales. At a specific timescale, the D-DPRR index provides clarity on the influence of factors on PRR at distinct time points. The results of the D-DPRR index are presented using heatmaps, where the vertical axis represents different timescales and the horizontal axis represents specific time points. Heatmaps prominently illustrate the variations in the D-DPRR index across timescales, highlighting the uncertainty of different factors' impacts on PRR.

Special comments

Line 133: It is recommended to convert the runoff volume of 8.09 billion m^3 to runoff depth in mm to facilitate comparison with the precipitation amount of 572 mm.

Reply: Thank you for the Referee's suggestion. We change "8.09 billion m^3" to "60 mm". The relevant descriptions will also be revised in Section 2.1 of the revised manuscript.

On the Impact of Human Activities on Hydrological Processes: The discussion section should incorporate insights from other models addressing similar topics to enhance the generalizability of the paper's conclusions. It is recommended to consult the following paper for a more comprehensive analysis:[1]Yang, X., Wu, F., Yuan, S., Ren, L., Sheffield, J., Fang, X., ... & Liu, Y. (2024). Quantifying the Impact of Human Activities on Hydrological Drought and Drought Propagation in China Using the PCR-GLOBWB v2. 0 Model. Water Resources Research, 60(1), e2023WR035443. [2] Wu, F., Yang, X., Cui, Z., Ren, L., Jiang, S., Liu, Y., & Yuan, S. (2024). The impact of human activities on blue-green water resources and quantification of water resource scarcity in the Yangtze River Basin. Science of the Total Environment, 909, 168550.

Reply: We agree with the Referee's suggestion. Yang et al. (2024) investigated the impact of anthropogenic factors on water resources in China's nine major river basins, integrating data on domestic, industrial, and irrigation water use. Wu et al. (2024) analyzed the effects of anthropogenic factors on water resources in the Yangtze River Basin, focusing on domestic, industrial, livestock, and irrigation activities. The findings of these studies indicate that population growth and urban expansion, along with behaviors such as local water extraction and inter-basin water transfers, significantly influence the PRR. Relevant studies have been referenced and discussed in the *Discussion* section.

Lines 158-164: The selected datasets are in raster format, while time series data are used in the calculations. There is a lack of processing for the raster data.

Reply: Thank you for the Referee's suggestion. The processing of NDVI data involves averaging the raster data within each study area. For ISR data, the number of impervious surface rasters within each study area is divided by the total number of rasters. NTL data is processed by summing the nighttime light intensity within each study area. Similarly, POP data is processed by summing the population within each study area. The relevant content has been supplemented in Section 2.2 of the revised manuscript.

Line 233: Verify the description of the value range here. Should this refer to the value range of bandwidth ω?

Reply: Thank you for the Referee's reminding. The search space for w is set to [0.05, 1.95] with a step size of 0.05. The relevant content has been revised in Section 3.2 of the manuscript.

References

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Fang, Y. and Jawitz, J. W.: The evolution of human population distance to water in the USA from 1790 to 2010, Nat. Commun., 10, 430, https://doi.org/10.1038/s41467-019-08366-z, 2019.

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