**General comments**

**Comments 1: Table 3** Why are the attributes in Table 3 selected based on the coefficient of variation?

**Response 1:** Thank you for your valuable comments on our research. The attributes in Table 3 were selected based on the coefficient of variation (CV) as it serves as a measure of relative variability, which is particularly useful in identifying the most stable attributes within each catchment cluster. By focusing on the attributes with the lowest and second lowest CV, we aimed to highlight those that exhibit consistent behavior across different catchments within each climate region, making them more representative of the typical characteristics of the clusters. Additionally, using CV allows us to account for the inherent variability of the dataset, thereby ensuring that the selected attributes are robust and not unduly influenced by outliers or extreme values. Scaling these attributes by the mean CV of the dataset further normalizes the variability, providing a clearer comparison between the clusters.

To enhance the clarity of the manuscript, we will add a detailed explanation in the text to further justify the use of the coefficient of variation (CV) for describing the attributes of catchment clusters. Once again, thank you for your valuable feedback, which has helped us improve the clarity of our work.

**Comments 2: Figure 2** It is suggested to include an explanation of the d-matrices in the methodology. Consider moving the statement “Vesanto (1999) suggested that SOM results can be expressed in the form of two types…” from L279 to section 2.1.2 and expand on it in more detail.

**Response 2:** Thank you for your constructive suggestion. We agree that an explanation of the d-matrices in the methodology would improve the clarity of the manuscript. We will expand on this concept by providing a more detailed description of the d-matrices in Section 2.1.2, where we will explain their role and how they are derived in the context of the self-organizing map (SOM) methodology.

Additionally, we will move the statement "Vesanto (1999) suggested that SOM results can be expressed in the form of two types⋯" from Line 279 to Section 2.1.2, as you suggested. This will allow us to elaborate further on this aspect and provide a clearer explanation of how the results are represented in the SOM framework.

Thank you for your valuable feedback, which has helped us improve the clarity and rigor of our work.

**Comments 3: Figure 3** Consider adjusting the color band so that the color corresponding to 0.5 is set to white. This would better highlight basins belonging to a cluster with higher confidence.

**Response 3:** Thank you for your valuable suggestion. We agree that adjusting the color band will improve the clarity of the distribution in Figure 3, particularly in better highlighting the basins with higher confidence that belong to the clusters. We will adjust the color band corresponding to membership values less than 0.5 to white, ensuring that the visual representation more effectively distinguishes basins with different levels of confidence. This adjustment will further enhance the interpretability of the results.

**Comments 4: Figure 6** It is recommended to use different color schemes for the third and fourth categories, as their current colors are too similar and not effective.

**Response 4:** Thank you for your helpful suggestion. We agree that the current color scheme for the third and fourth categories in Figure 6 is too similar and may cause confusion. We will modify the color scheme to select more distinct colors for these two categories, ensuring a clearer visual distinction between them. This change will help enhance the figure's effectiveness in presenting the data.

**Comments 5: Figure 7** Consider clearly marking the boundaries of each climate zone in the figure and labeling the basin class in the subplots.

**Response 5:** Thank you for your valuable suggestion regarding Figure 7. In the original version, we used gray solid lines to delineate climate zone boundaries and labeled the climate regions. To address your feedback, we will enhance the figure by using more distinct colors and labels to clearly highlight the boundaries of each climate zone. Additionally, we will label the basin classes in the subplots. These improvements will help enhance the readability and clarity of the figure. We appreciate your constructive input, which has strengthened the clarity of our visual presentation.

**Comments 6: Introduction** The paper overlooks previous catchment classification studies conducted in China:

Luo, K. (1954) Draft of natural geography regionalization of China. (in Chinese)

罗开富,1954. 中国水文区划草案.

Xiong, Y., Zhang, J., et al. (1995) Hydrology Regionalization of China, Science Press, Beijing.(in Chinese)

熊怡,张家桢,等,1995. 中国水文区划. 科学出版社

Liu, C., Zhou, C., et al. (2014) Chinese Hydrological Geography, Science Press, Beijing

刘昌明，周成虎等，2014. 中国水文地理. 科学出版社

Xu, H., Wang, H., Liu, P. (2024). Identifying control factors of hydrological behavior through catchment classification in Mainland of China. Journal of Hydrology, 645, 132206. DOI: 10.1016/j.jhydrol.2024.132206

**Response 6:** Thank you for pointing out these important references. We appreciate your suggestion to include previous catchment classification studies conducted in China. We acknowledge the valuable contributions of Luo (1954), Xiong et al. (1995), Liu et al. (2014), and Xu et al. (2024) in this field. In response, we will expand the introduction after Line 66 to include a discussion of these studies and their relevance to our work. This will provide a more comprehensive background for our research and highlight how our approach builds on and complements the existing studies in China.

**Comments 7: Methodology** In L180, the author claims FCM has “low sensitivity to initialization.” I am curious if this is the case, and it might be beneficial to demonstrate FCM results under multiple initializations.

**Response 7:** Thank you for raising this important point regarding the sensitivity of Fuzzy C-Means (FCM) clustering to initialization. While FCM is generally considered less sensitive to initialization compared to hard clustering methods like K-Means, we acknowledge that initialization can still influence the results, particularly in complex, high-dimensional datasets. To address this concern and strengthen the robustness of our findings, we propose the following actions:

- **Clarification of the Statement:**

We will revise the statement in Line 180 to more accurately reflect the behavior of FCM. Instead of claiming that FCM has "low sensitivity to initialization," we will state that FCM is "relatively less sensitive to initialization compared to hard clustering methods, but initialization can still affect the results, particularly in high-dimensional datasets."

- **Demonstration of FCM Results Under Multiple Initializations:**

To empirically demonstrate the impact of initialization on FCM results, we will conduct additional experiments with multiple initializations. Specifically, we will run the FCM algorithm 10 – 20 times with different random initializations and compare the resulting cluster memberships and centroids.

We will include a brief analysis of the variability in cluster results across initializations, such as the average difference in membership values or the stability of cluster centroids. This will provide quantitative evidence of the sensitivity (or lack thereof) of FCM to initialization in our specific application.

By addressing this comment, we aim to provide a more rigorous and transparent analysis of the FCM algorithm's behavior in our study. Thank you for your insightful feedback, which has helped us improve the methodological robustness of our work.

**Comments 8: Methodology** It is suggested that the methods used in the results section be introduced in the methodology, highlighting the logic and approach rather than just detailing the SOM and FCM algorithms. A flowchart would be helpful if possible.

**Response 8:** Thank you for your valuable suggestion. We agree that the methodology section should provide a clearer and more comprehensive explanation of the overall logic and approach used in the study, rather than focusing solely on the technical details of the Self-Organizing Maps (SOM) and Fuzzy C-Means (FCM) algorithms. To address this, we will revise the methodology section to include the following improvements:

- **Enhanced Explanation of Logic and Approach:**

We have introduced a dedicated section at the beginning of the methodology to outline the overall workflow and rationale for integrating Self-Organizing Maps (SOM) and Fuzzy C-Means (FCM) clustering for catchment classification. To further enhance clarity, we will expand this section to include a discussion of why these methods were chosen, how they complement each other, and how they address the challenges of classifying catchments across diverse hydroclimatological and geomorphological conditions.

Additionally, we will explicitly state the steps involved in the process, such as data preprocessing, variable selection, dimensionality reduction, clustering, and validation, to provide a logical flow of the methodology.

- **Addition of a Flowchart:**

A flowchart will be added to visually summarize the methodological steps, from data collection and preprocessing to the final classification and validation. This will help readers better understand the sequence of operations and the relationships between different components of the methodology.

By addressing this comment, we aim to provide a more rigorous and transparent explanation of our methodology. Thank you for your insightful feedback, which has helped us improve the clarity and logical flow of our work.

**Comments 9: Methodology** How to classify catchment from climate region to basin class? FCM? If so, are the inputs to FCM the features in Table 1 or their principal components?

**Response 9:** Thank you for your question regarding the classification process from climate regions to basin classes. We appreciate the opportunity to clarify the methodology and ensure it accurately reflects the steps taken in the study. Below, we provide a detailed explanation of the two-step classification process used in our research.

- **The classification process involves two main steps:**

Step 1: Climate Region Classification

The SOM-FCM algorithm is first applied to classify catchments into climate regions. In this step, the inputs to the SOM algorithm are the climate indices derived from the data preparation process described in Section 2.1.1 (Selection of Climate Indices). These indices capture key meteorological characteristics, such as aridity, temperature, and precipitation patterns. The SOM algorithm reduces the high-dimensional climate data into a 2D map of neurons, which is then clustered using FCM to define distinct climate regions. This step ensures that catchments within each climate region share similar meteorological properties.

Step 2: Basin Classification within Climate Regions

Within each climate region, the SOM-FCM algorithm is applied again to classify catchments into basin classes. Here, the inputs to the SOM algorithm are the principal components of the catchment descriptors (derived from the original features listed in Table 1). These principal components reduce the dimensionality of the data while retaining the most important variability in both climate and geomorphological

characteristics. The output neurons (weight vectors) from the SOM algorithm, which represent the reduced-dimensional representation of the original features, are then clustered using FCM to define basin classes. This step ensures that catchments within each basin class share similar hydrometeorological and geomorphological characteristics.

- **Rationale for Using Principal Components**

Principal component analysis (PCA) is employed to address multicollinearity among the input variables and improve computational efficiency. By transforming the original features into principal components, we reduce redundancy while preserving the essential information needed for classification. The SOM algorithm further processes these principal components into a 2D representation, which is then used as input to FCM for clustering. This approach ensures a robust classification that captures both broad-scale climate patterns and fine-scale geomorphological variations.

To address this comment and accurately reflect the methodology, we will revise the methodology section to explicitly describe the two-step SOM-FCM process and clarify the inputs to each step. By doing so, we aim to provide a clearer and more accurate explanation of the classification process. Thank you for your insightful feedback, which has helped us improve the methodological rigor and clarity of our work.

**Comments 10: Results** Were the selected 10 small watersheds affected by human activities, such as agricultural water use or urban consumption? Would this impact the results?

Using 10 small watersheds for validation might be insufficient. If the author is willing, more runoff data can be found in NESSDC (https://www.geodata.cn), such as:

DOI: 10.12041/geodata.30184613892738.ver1.db

DOI: 10.12041/geodata.69811525443157.ver1.db

DOI: 10.12041/geodata.31258482188424.ver1.db

**Response 10:** Thank you for your insightful comments regarding the potential impact of human activities on the selected small watersheds and the valuable suggestion to expand the validation dataset. We appreciate your feedback, which has helped us identify areas for improvement in our study. Below, we address your concerns and outline the steps we will take to enhance the robustness of our results.

- **Impact of Human Activities on Selected Watersheds:**

The 10 small watersheds selected for validation were chosen based on the criteria of being unregulated catchments with minimal human interference, as stated in Section 3.3. This selection was made to ensure that the hydrological behavior of these catchments primarily reflects natural processes rather than anthropogenic influences. However, we acknowledge that even in unregulated catchments, low-level human activities (e.g., agricultural water use or small-scale urban consumption) might still exist and could potentially impact the results. To address this, we will conduct a detailed analysis of land use data for each catchment to assess the extent of human influence. This analysis will be included in the revised manuscript, and any catchments showing significant human impact will be either excluded or discussed in the context of their potential effects on hydrological signatures. We agree that future studies should incorporate more detailed assessments of anthropogenic impacts to further improve the reliability of catchment classification.

- **Expanding the Validation Dataset:**

We greatly appreciate your suggestion to use additional runoff data from the National Earth System Science Data Center (NESSDC). We will incorporate the datasets you recommended (DOIs: 10.12041/geodata.30184613892738.ver1.db, 10.12041/geodata.69811525443157.ver1.db, and 10.12041/geodata.31258482188424.ver1.db) to expand our validation dataset. By including more catchments, We will be able to validate the classification approach across a wider range of hydrological conditions, ensuring its applicability to diverse environmental settings, while also assessing the generalizability of the results to other regions in China, particularly those with varying climate and landscape characteristics. Thank you for your valuable feedback, which has significantly improved the quality of our work.

**Comments 11: Discussion** The discussion needs to emphasize the connection with the results. Currently, the discussion section seems to introduce existing knowledge within the basin. Perhaps discussing similarities and differences with similar studies, limitations, and potential applications would be more effective.

**Response 11:** Thank you for your valuable feedback regarding the discussion section. We agree that the discussion should more effectively emphasize the connection with

the results, highlight similarities and differences with similar studies, and address the limitations and potential applications of our work. Below, we outline the revisions we will make to address these points.

- **Emphasizing the Connection with Results**

We will revise the discussion to explicitly connect our findings to the validation results. we will discuss how the seasonal flow regimes and flow duration curves (FDCs) observed in the 10 small catchments (and the expanded dataset) support the effectiveness of our classification approach. We will also highlight how the differences in hydrological behavior between catchments in different climate regions align with the classification results and provide insights into the underlying hydrological processes.

- **Comparing with Similar Studies**

We have explored in the discussion section that climate and watershed characteristics can exhibit similar hydrological behavior, and we will build on this to compare with similar studies using other clustering methods for catchment classification. We will also highlight the unique aspects of our approach, such as the integration of SOM and FCM and the use of both climate and geomorphological characteristics, and how these contribute to the improved classification of catchments.

- **Highlighting Potential Applications and Limitations**

We will expand the discussion to highlight the potential applications of our classification approach. we will discuss how our method can be used to improve hydrological modeling in ungauged catchments, support water resource management, and inform climate change adaptation strategies. We will add a dedicated subsection to discuss the limitations of our study. We will acknowledge the potential impact of human activities on the selected catchments and the challenges of generalizing our results to regions with significant anthropogenic influences.

Thank you for your valuable feedback, which has significantly improved the quality of our work.

**Comments 12: Discussion** The features used in this paper do not consider any human activities. How might this affect the results of catchment classification? Given the significant human activities in many regions of China, how should we interpret or use the classification results obtained without considering human activities?

**Response 12:** Thank you for your valuable feedback. The features used in our study (climate indices and geomorphological characteristics) do not explicitly account for human activities. While this allows us to focus on natural hydrological processes, it may limit the applicability of our classification results in regions where human activities significantly alter catchment behavior. We will add a discussion of how human activities might affect the results of catchment classification. We discuss how in areas with significant agricultural or urban development, human activities can outpace natural hydrological processes, leading to deviations from the patterns identified in our study.

we will suggest that our classification results are most applicable in regions with minimal human impact, such as remote or protected areas. For regions with significant human activities, we will recommend combining our classification framework with additional data on land use, water management practices, and other anthropogenic factors to improve the accuracy of hydrological modeling and predictions.

We will further refine this part to ensure that our research contributions and innovations are clearly explained. Thank you again for your feedback, and we will make the necessary improvements based on your suggestions.

**Comments 13: L460-471** This part is not easy to understand. Especially, I didn't understand this sentence: L464 “The flow regime in climate region II presented multiple peaks following multiple peaks in precipitation in June and July during the same period.”

**Response 13:** Thank you for your valuable feedback on our manuscript. We agree that this section could be more clearly written to improve readability and ensure that the findings are easily understood. we will provide a revised version of this paragraph, with a clearer explanation of the flow regime patterns in climate region and their relationship to precipitation.

Thank you again for your feedback, and we will make the necessary improvements based on your suggestions.

**Comments 14: L495-498** What do “combined indicators” refer to? What does “at different scales” mean? Basin area? Time?

**Response 14:** Thank you for your question regarding the terms "combined indicators" and "at different scales" in Lines 495–498. We agree that these terms require

clarification to ensure readers fully understand their meaning and significance within the context of our study.

We will clarify that "combined indicators" refer to the integration of climate indices (e.g., moisture index, temperature, snow fraction) and geomorphological characteristics (e.g., elevation, slope, soil texture) used in our classification framework. These combined indicators capture both climatic and landscape factors that influence hydrological behavior. To avoid ambiguity, we will revise the relevant terms to make their meaning clearer.

Additionally, we will clarify that "at different scales" refers to both spatial scales (e.g., basin area, regional and local patterns) and temporal scales (e.g., seasonal runoff, flood events). This reflects the multi-scale nature of hydrological processes, which are influenced by both large-scale climate patterns and small-scale landscape features. Specifically, climate patterns primarily influence seasonal runoff (medium- to long-term scales), while landscape characteristics play a more significant role in flood events (short-term scales). To eliminate ambiguity, we will explicitly use the terms "spatial scale" and "temporal scale" in the revised manuscript.

Once again, thank you for your valuable feedback, which has helped us improve the clarity of our work. We will make the necessary adjustments in the revised manuscript.

**Comments 15: L560-561** What does “There is no particular classification for one catchment that allows greater flexibility in the selection of a catchment for comparative studies or parameter transplantation in ungauged catchments” mean?

**Response 15:** Thank you for your valuable feedback. we will provide a revised explanation to clarify the flexibility offered by our classification approach in selecting catchments for comparative studies or parameter transplantation in ungauged catchments.

The phrase "no particular classification for one catchment" is ambiguous and could be misinterpreted. It is intended to highlight that our classification framework does not rigidly assign a single classification to each catchment but instead allows for flexibility through the use of the SOM-FCM algorithm. we will include a brief explanation of how this flexibility benefits hydrological modeling and regionalization studies. The ability to identify catchments with overlapping characteristics supports more accurate parameter transplantation, as it accounts for the gradual transitions in hydrological

behavior between catchments. This approach is particularly valuable in regions with high spatial variability, where rigid classifications may fail to capture the complexity of hydrological processes.

We will further refine this part to ensure that our research are clearly explained. Thank you for your valuable feedback, which has helped us improve the clarity of our work.

**Comments 16: L556-557** The statement "Moreover, climate-homogeneous regions respond to hydrological behaviors at medium- or longtime scales, whereas catchment classification regulates hydrological processes at the flood event scale" needs to be strengthened in the results to support this conclusion.

**Response 16:** Thank you for your valuable comments. We agree that this conclusion needs stronger support from the results to ensure its validity and clarity. Below, we propose revisions to strengthen the connection between this statement and the results presented in the study.

We will revise the discussion to explicitly link this conclusion to the results presented in Section 3.3 (Validation Results for Small Catchments in China). Specifically, we will reference the seasonal flow regimes (Fig. 7) and flow duration curves (Fig. 8) to demonstrate how climate-homogeneous regions influence medium- to long-term hydrological behaviors and how catchment classification regulates flood event-scale processes. And we will also provide additional analysis or examples from the results to reinforce this conclusion.

We sincerely appreciate the reviewer's insightful suggestion, which has helped us improve the clarity and rigor of our work.