Responses to reviewers

Dear Editors and Reviewers,

Thank you very much for your time and effort for reviewing the article initially titled "Impacts of science on society and policy in global river basins" (hess-2024-72). We really appreciate all of your insightful comments.

We have revised the article title to "Impacts of science on society and policy in major river basins globally" to better reflect the scope of the study, and provided a revised version of the manuscript (changes marked in <mark>yellow highlights</mark>). Hatch patterns have been added to figures with multiple colors for readers with color vision deficiencies.

We have also provided point-by-point responses to each of your comments in black font along with corresponding line numbers (in **bold**) in the revised manuscript below:

RC1: Comment on hess-2024-72

The manuscript systematically elaborates on the knowledge system of key river. Among them, the key processes and algorithms has its further selection principles or unique applicability, and there is a detailed introduction. This is very important in the evaluation of knowledge system services and is more conducive to comparison between different studies. However, after overall review, there are still many doubts regarding the following:

Overall Comment:

(1) Formula Standardization

There are descriptive words in formulas 1, 2, and 3 in the manuscript. Please explain the variables and their meanings in a more explicit way (e.g. "where, x is … " in Eq.3), and use a more explicit variable calculation form to present the "median" (Eq.3).

Thank you for your comments. We have refined and added further explanations for Eq.1-3 as follows **(Line 55-65, Line 160-165):**

For any discipline-issue network i:

$$DM_i = \frac{2C_d}{n(n-1)} \qquad (Eq.1)$$

where DM_i is the Degree of Multidisciplinarity value of a discipline-issue network i, C_d is the total number of existing connections between any issue and discipline d in the network, and n is the total number of d in the network.

For any issue network i:

$$DI_i = \frac{\sum_n C_m}{n} \qquad (Eq.2)$$

where DI_i is the Degree of Issue-connectivity of an issue network i, C_m is the number of adjacent connections to any specific issue m, and n is the total number of m in the network.

The Sen's slopes (Sen, 1968) were then used to measure the magnitudes of the trends as Eq.3:

$$d_{Sen} = \tilde{d} \left(\frac{x_j - x_i}{j - i}\right) \text{ for } 1 \leq i < j \leq n \qquad (Eq.3)$$

where $\tilde{d}$ is the median value separating the higher 50% from the lower 50% of the indicator value x in the time series, i and j are adjacent time points, and n is the total number of time points.

(2) Structural Issues

Can the representation of the framework in Section 2 be considered as a preface to the Methods section? Among them, the density of the discipline-issue network and the calculation method for the degree centrality of the issue network are all in the Section 3. It becomes clearer whether they can be merged.

Thank you for your comments. We have integrated Section 2 into the Method section as a new Section 2.1, and consolidated the descriptions of the framework and relevant calculations about the discipline-issue network and the issue network in the new Section 2.1 (**Line 40-90**).

(3) Comprehensive Knowledge Structure

The selection of 72 river basins is mostly typical of river systems in various continents, and is also significantly influenced by human activities. And the information must also be relatively detailed, which is a necessary foundation for this research method. However, can the representativeness of social and policy analysis be highlighted based on existing analysis results? ("Abstract: …Evaluating these structural characteristics against 6 impact indicators on society and policy, over 90% of rivers were found to had knowledge structures that strongly linked to societal impacts whereas only 57% were to the policy…") After all, the title mentions global river basins, but currently the intuitive feeling is to search for conclusions in large rivers influenced by humans, which always feels somewhat inappropriate. Please take above concern into consideration.

Additionally, why are there missing rivers in the North Asian region, such as the Ob River and Yenisei River basins? Will the North Asian rivers, which are relatively low in human activity, affect the relevant conclusions on policy and social impact in the abstract?

Thank you for your comments. The 72 river basins were selected based on those receiving the highest numbers of publications in the WoS database. We chose peer-reviewed publications in the WoS as our data source as it provides consistent, systematic documentation of scientific knowledge development across a broad range of disciplines for a long timeframe. At least one river basin in each of the continents was included for the spatial representativeness of this study. This is clarified in the method section (**Line 115-120**).

However, we agree that there is a potential bias towards large river basins with societal and natural significance to be studied, and some rivers may not be included due to comparatively fewer publications in the WoS. For example, the Lake Baikal catchment was studied, which was a major part of the Yenisei River. We have recognized it as a limitation in the discussion section **(Line 400-405)**.

In addition, we will change our title as "Impacts of science on society and policy in major river basins globally".

(4) Support for key conclusions in the manuscript

The following sentence is an explanation of the key conclusions in the abstract ("Abstract: …over 90% of rivers were found to had knowledge structures that strongly linked to societal impacts whereas only 57% were to the policy"). However, is the R2 the smallest among the 41 basins greater than 0.3, or is the mean of the 41 basins greater than 0.3? The R2 value is indeed a bit low, and the correlation explanation is weak; But it is possible that in such studies, more than 0.3 has already met the interpretive requirements. The manuscript can supplement the general situation of R2 in similar studies and compare the level of 0.3. To enhance the reliability of the conclusions of this article.

" The structural characteristics of the knowledge systems had been strongly linked to the society indicators with over 90% river basins had acceptable regression model fits, but much weaker with the policy indicators as only 41 river basins had two or more linear models that validated the relationships between their knowledge systems and the policy (adjusted R2 > 0.3, statistical significance p < 0.05). "

Thank you for your comments. The R^2 values in this study were estimated in each regression model for each river basin, and any models with R^2 values smaller than 0.3 were grouped into the 'unclear knowledge-society' or 'unclear knowledge-policy' pattern.

The threshold of 0.3 was selected based on studies in conventional statistical regressions (Ratner, 2009; Royston, 2007), which identified 0.3 to have "weak" explanation power between the knowledge indicators and society/policy indicators. Similar thresholds between 0.2 and 0.3 have also been found by correlations between knowledge, attitudes, and practices regarding environmental problems (Afroz & Ilham, 2020; Alias, 2019). In general, a recent meta-analysis (Hernanda et al., 2023) indicated an acceptable range for correlation levels to be 0.26 to 0.48 across 23 studies published from 1999 to 2022. We have provided this additional justification in the method section **(Line 180-185)**.

(5) Section of "Data and code availability"

(Only representing personal opinions) Compared to conclusive summaries, collecting and organizing information and making accurate judgments in the process will be more important. Can the manuscript be supplemented with information about the data or list of statistically

Thank you for your comments. We have provided an Appendix with additional explanations for each section detailing the data information and statistical analysis conducted to support the results in the manuscript (**Line 420-490**).

R codes used to generate the results were also commented and deposited in the public repository Github (https://github.com/SLWU423/Code-for-global-river-basin-science-policy-society-impact) for reproduction of the results and further research development (**Line 490-495**).

Thank you for your comments. We refrained from introducing additional subjective bias to define a specific threshold value for DM and DI, and considered the comparative values of DM and DI among the 72 river basins. Therefore, the low and high DM and DI were determined by their z-scores:

For any river basin k, and any knowledge, societal, and policy indicator x:

$$x'_k = \frac{x_k - \overline{x_k}}{\sigma_k} \qquad\qquad (Eq.4)$$

where x'_k is the z-score of any knowledge, societal and policy indicator of x_k, $\overline{x_k}$ is the mean value, and σ_k is the standard deviation (**Line 170-175**).

Therefore, we determined the division between 'low' and 'high' scores by the zero value of z-score. A z-score above zero means that the DM or DI value is above the average value for all rivers, and therefore having a 'high' DM or DI. Similarly, a z-score value below zero will be considered having a 'low' DM or DI. This has been clarified in **Line 65-85**.

We have also increased the resolutions and fonts for all figures for improved clarity in the revised manuscript.

Thank you for your comments. We have removed the proportion values and reformatted all tables in Appendix A (**Line 420-425**).

RC2: Comment on hess-2024-72

This study on the impacts of scientific knowledge development on society and policy within global river basins is both timely and insightful. The framework for measuring knowledge systems through network dimensions of multidisciplinarity and issue-connectivity is commendable. Here are some review comments:

Framework and Methodology: Elaborate on the theoretical underpinnings of your proposed framework and discuss its potential for long-term applicability.

Thank you for your comments. We have consolidated the theoretical underpinning that supports the knowledge network construction in a new Section 2.1 (**Line 40-50**). Specifically: "Built on the Science of Science (SoS) theory (Zeng et al., 2017), a knowledge system is understood as a dynamic system, consisting of knowledge from different disciplines and issues studied, with complex and co-evolving relationships between them, as Latour (1987) described "*knitting, weaving and knotting together into an overarching scientific fabric*" (Latour, 1987; Shi et al., 2015). We adopt a network-based framework to evaluate such interactions (Coccia, 2020; Sayles & Baggio, 2017; Wei et al., 2022; Wu et al., 2021).We characterize the knowledge system as a discipline-issue network, where connections are established between issues and the disciplines used to address the issues (Callon et al., 1983; Noyons, 2001)."

We have also added an additional section in the Discussion section elaborating the implications of the framework (**Line 385-395**). Specifically: "Our network-based framework contributes to advancing the Science of Science (Zeng et al., 2017) and transforming knowledge for more sustainable river basin development. It provides a method to explicitly measure the structure of knowledge as a discipline-issue network system, which guides future knowledge development by identifying explicitly where and what to change or connect between disciplinary knowledge and issues at hand, therefore assisting in more suitable, more precise, and more predictable knowledge development. Moreover, our framework links the structural configurations of knowledge systems with developments in society and policy, thus contribute to better evaluation of research outcomes and action-oriented research for specifying "credible, legitimate, and relevant" in good governance (Cash et al., 2003; Kim, 2019). Finally, this framework will contribute to river basin management by enabling comparisons of knowledge development for river basins with varying management issues of focuses and contexts, thus enables the design of tailored management strategies and co-learning according to different patterns of connections among river basin knowledge, society, and policy development."

Data and Analysis: Consider the inclusion of additional data sources beyond Web of Science, such as conference papers or government reports, to enhance the study's comprehensiveness.

Thank you for your comments. This study focused on the science-driven knowledge development, by using peer-reviewed articles indexed in the Web of Science (WoS) database. The WoS database was chosen because it provides consistent, systematic documentation of knowledge development across a broad range of disciplines for a long timeframe. However, we do acknowledge that use of additional data including conference paper, and government

reports also contributes to the river basin knowledge development, which tends to focus on the practice-driven knowledge. This has been recognized as a limitation in the discussion section (**Line 395-405**).

Address the potential variability in keyword extraction and clustering across different languages and regions.

Thank you for your comments. This study focused on extracting English keywords from scientific publications, and how knowledge development differed across different river basins globally. Other languages were not included for keyword processing.

We have justified this limitation in the Discussion section (**Line 395-405**): English remains the most used language for knowledge development across different regions, and many academics with other language backgrounds wrote in English in studying for wider dissemination of findings on their river basins (Ramírez-Castañeda, 2020).

Results Interpretation: You note a strong correlation between knowledge structures and societal impacts, but a weaker link with policy. What might account for this discrepancy? Further analysis or discussion on this point would be beneficial.

Thank you for your comments. The weak link between knowledge and policy can be attributed to the challenge of productive knowledge transfer on decision making, which is commonly studied by research at the science-policy interface (Louder et al., 2021; Nguyen et al., 2017). We have provided additional discussions under the subtitle of "Challenges at the knowledge-policy interface" in the Discussion section (**Line 355-370**), specifically:

"Over 90% of the river basins had knowledge structures that strongly linked to the society indicators but only 57% of rivers had statistically significant relationships with the policy indicators (Fig. 4). This is closely related to the challenge of knowledge transfer on decision making at the science-policy interface (Louder et al., 2021; Nguyen et al., 2017). Such challenge has been widely recognised as policy and practice decisions are informed by diverse values and beliefs, multiple sources of knowledge, and are shaped by cognitive factors and power dynamics beyond the direct influence of research activities (Hakkarainen et al., 2020; Pitt et al., 2018; Posner & Cvitanovic, 2019). We propose to develop "boundary spanners" as a potential solution (Edwards & Meagher, 2020). These spanners could be creditable academic organizations for the policy community, individual or groups of scientists or professional consultants who facilitate knowledge and information across otherwise disconnected communities and synthesize different values and insights to facilitate collective sense-making (Bodin, 2017; Stovel & Shaw, 2012). They not only can bridge disciplinary silos for natural and social scientists, but more importantly able to coordinate scientists with local stakeholders and policy-makers with different levels of management powers and contexts. Additionally, although beyond the scope of this study, we recognize the interactions between society and policy. In particular, the SO in society indicators and the RU in policy indicators were most

strongly positively correlated (r = 0.81, p < 0.05) (Fig. B5), which indicates a need to recognise the connections between policy and society development and their spill-over effects on knowledge in future study. ”

Discussion and Conclusions:

You highlight the importance of interdisciplinary research, particularly in Asian, African, and South American river basins. Could you suggest specific strategies to foster such research in these areas?

Thank you for your comments. We have more thoroughly discussed knowledge development in Asian, African and South American river basins in the revised manuscript under the subtitle "Tailored knowledge strategies based on knowledge-society-policy patterns" in the Discussion section (**Line 370-385**). Specifically:

"The integrated knowledge structure was identified to be most desirable, which links with the Knowledge For Environment (KFE) and the Knowledge For Resource Availability (KFA) patterns. Issue-driven knowledge structures were identified to have similar optimized society and policy impacts to the integrated knowledge structure, whereas discipline-driven knowledge structure was not effective in optimizing multiple society and policy indicators at the same time (Fig. 5 and Fig. C1). About 15% of the river basins studied in America, Europe and Oceania (e.g., the Amazon River, the Colorado River, the Danube River, and the Murray-Darling Basin) with integrated knowledge structures demonstrated more balanced impacts on society and policy (Fig. 5). They provide good examples for other river basins in achieving a holistic integration of science, society and policy. On the other hand, river basins with the Knowledge Against Environment (KAE) and the Knowledge Against Resource Availability (KAR) patterns are considered less desirable, as optimizing the current knowledge structure to reduce the negative environmental impacts or improving resource availabilities would be traded off with socio-economic development and governance capacities (Fig. 5). Rivers with fragmented knowledge structures comprising 35% of the river basins studied, mostly in Asia, Africa, and South America were most prone to these impact patterns (Fig. 3). It reflects the inevitable concerns and interests of these river basins with greater development pressures and inequalities. A more balanced and integrated knowledge development approach could be supported by raising awareness of human impacts on river basins, and targeted research fundings that facilitate bridging between science and policy (Jabbour, 2022; Matsumoto et al., 2020)."

The concept of "boundary spanning organizations" is introduced as a solution. Further details on the form and mechanisms of these organizations would be valuable.

Thank you for your comments. We have provided additional explanation on the "boundary spanning organization" in the Discussion section (**Line 360-365**). Specifically:

"We propose to develop "boundary spanners" as a potential solution (Edwards & Meagher, 2020). These spanners could be creditable academic organizations for the policy community,

individual or groups of scientists or professional consultants who facilitate knowledge and information across otherwise disconnected communities and synthesize different values and insights to facilitate collective sense-making (Bodin, 2017; Stovel & Shaw, 2012). They not only can bridge disciplinary silos for natural and social scientists, but more importantly able to coordinate scientists with local stakeholders and policy-makers with different levels of management power and contexts."

Overall, this manuscript is well-written, but certain sections could benefit from further linguistic refinement to enhance clarity and flow. This research provides valuable insights into the structure of scientific knowledge within global river basins and offers constructive strategies for sustainable development. I look forward to your feedback on these comments and the revised manuscript.

Thank you for your comments. We will carefully improve the clarity and flow of language in the revised manuscript.

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