Referee #1 Comments:

1. General comments:

Lee et al.'s study proposes a Human Social Sensing framework that performs text analysis to characterize changes in South Korean newspaper discourse concerning water between 1960 and 2020. The authors identify a shift from disaster response and infrastructure development toward water-quality management, environmental protection, and sustainability. These findings are largely descriptive. They are also reasonably intuitive given South Korea's broader transition toward stronger environmental regulation. Therefore, the scientific contribution to HESS appears extremely marginal.

More importantly, I struggled to identify what the manuscript teaches us about hydrological systems or human-water interactions in a manner that constitutes a substantive contribution to HESS. HESS publishes multidisciplinary research, but that interdisciplinarity is expected to advance hydrological science (HESS encourages and supports fundamental and applied research that advances the understanding of hydrological systems, their role in providing water for ecosystems and society, and the role of the water cycle in the functioning of the Earth system). In the present manuscript, no hydrological observations, processes, states, fluxes, or model outputs are analyzed. The study does not relate the derived discourse indicators to precipitation, floods, droughts, streamflow, water quality, water use, reservoir operations, or observed management responses. Instead, the connection to sociohydrology is developed primarily as a prospective application in the Discussion, rather than demonstrated within the analysis itself.

If the authors consider the manuscript to fall under # 3 of the HESS scope, they need to demonstrate that connection operationally rather than conceptually. For example, they could use a discourse indicator to estimate social memory decay after a major hydrological event. They could also test whether the indicators explain water-management or behavioral responses. Another option would be to incorporate an indicator into a coupled sociohydrological model. The authors could then test whether it improves the representation of an observed human–water feedback. Merely listing parameter calibration, proxy-variable, and lumped-model approaches without implementing and evaluating at least one of them is insufficient to establish a hydrological contribution.

Overall, I do not consider the manuscript suitable for publication in HESS in its present form and recommend rejection rather than major revision. The work may be better suited to a journal whose central remit includes environmental discourse, communication, policy, or social dimensions of environmental management. Potential journals could be Society and Natural Resources, Environmental Science and Policy, etc.

Response: We sincerely thank the reviewer for this careful and substantive assessment. We agree that the original manuscript did not make the connection between HSS-derived information and sociohydrological analysis sufficiently explicit. At the same time, we would like to clarify that the use of newspaper records, online search behavior, and other human-generated data to characterize otherwise difficult-to-observe social dimensions of water systems has precedent within hydrological science. For example, Wei et al. (2021) used newspaper articles together with sentiment and topic analyses in HESS to examine long-term changes in conflict and cooperation surrounding water events in the Lancang–Mekong basin. Lu et al. (2021), also in HESS, subsequently used sentiment information derived from newspaper articles as empirical information for evaluating the social component of a coupled sociohydrological model of transboundary cooperation. Related work in Water Resources Research has used online search behavior to characterize drought-related public attention in analyses of water conservation and rebound dynamics (Gonzales and Ajami, 2017). These studies establish an important precedent for using indirect, human-generated observations to investigate social processes that interact with water systems. We have revised the manuscript to position HSS more clearly within this existing line of sociohydrological research, rather than implying that the use of textual or digital records itself constitutes the principal novelty of the study.

The contribution of HSS is instead to extend this line of work as a more general framework for recovering long-term and multidimensional empirical information about otherwise poorly observed social processes. First, the newspaper archive allows social-discourse dynamics to be reconstructed over approximately six decades, addressing a temporal mismatch between long-term sociohydrological dynamics and many available social datasets, particularly newer digital traces such as online search records. Second, rather than deriving a single measure such as media volume, search frequency, or sentiment, HSS combines multiple observable dimensions of discourse, including theme prevalence, framing prevalence, keyword importance, semantic relationships, topic prevalence, and their temporal evolution. Most importantly, the revised HSS framework explicitly distinguishes three levels that should not be conflated: directly observed discourse quantities, derived HSS indicators or proxies, and latent social constructs represented in sociohydrological theory or models. Thus, for example, an increase in environmental-sustainability framing is not interpreted as a direct measurement of environmental awareness. Instead, its temporal trajectory provides empirical information potentially relevant to evaluating or constraining the direction and timing of an otherwise poorly observed environmental-awareness state, while retaining uncertainty associated with sampling, source selection, editorial framing, and the mapping from discourse to the latent construct. We believe this explicit observation $\rightarrow$ proxy $\rightarrow$ latent-state structure, together with the long temporal coverage and multidimensional characterization of discourse, represents the main methodological contribution of HSS beyond earlier applications of newspaper or online data in sociohydrology.

Accordingly, in the revised manuscript we have (1) reformulated the research questions to more clearly define the hydrological problem addressed by the study, (2) clarified the methodological contribution of the proposed HSS framework as a means of transforming discourse-derived information into measurable social indicators, (3) added a simplified quantitative demonstration showing how the relative prevalence of economic-development and environmental-sustainability framings in newspaper discourse can be converted into an empirical discourse indicator whose temporal evolution may provide information relevant to a latent environmental-awareness state represented in sociohydrological models (e.g., van Emmerik et al., 2014), and (4) strengthened the discussion of how such empirically derived indicators can contribute to the representation of coupled human–water feedbacks. The purpose of this demonstration is not to present a fully calibrated coupled model, but to show explicitly how an HSS-derived indicator can move from discourse analysis to a model-relevant social variable. We believe that these revisions directly address the reviewer's central concern regarding the hydrological relevance of the study and will make the contribution of HSS to sociohydrological analysis substantially clearer.

2. Specific comments:

1) Introduction: What specific research question is the manuscript trying to answer? The general objective is stated, but the scientific question remains unclear. The authors should also explain why this question matters beyond documenting a historical change in newspaper discourse.

Response: Thank you for this important comment. We agree that the previous manuscript stated an objective but did not clearly articulate the underlying scientific question.

We have now reformulated the study around whether long-term media discourse can be transformed into reproducible indicators that provide empirical information about latent social processes relevant to sociohydrological dynamics. This shifts the focus from simply documenting historical newspaper trends to addressing the observability of social components in human–water systems.

Accordingly, the revised Introduction now reads:

“A persistent challenge in sociohydrology is that important social processes, including environmental awareness, collective memory, and changing management priorities, are difficult to observe continuously over the long periods represented in coupled human–water models. This raises a fundamental measurement question: can historical human-generated records be systematically converted into empirical indicators that provide information about these latent social dynamics? We investigate this question using long-term newspaper discourse as an observable record of changing water-related framing while explicitly recognizing that media discourse is not equivalent to public perception.”

2) The authors should clarify the specific gap that HSS fills in hydrology and sociohydrological modelling. The important challenge is not simply improving text-mining methods but converting latent and usually unobserved social constructs into measurable variables or parameters that can be used in a sociohydrological model. How does the proposed framework accomplish this conversion, and which model components does it help constrain, how it is operationally used?

Response: We thank the reviewer for identifying this central issue. We agree that the relevant gap is not a lack of text-mining techniques, but the difficulty of deriving empirical information about latent and poorly observed social processes that are represented in sociohydrological models.

We have therefore revised the manuscript to distinguish three levels of information: directly observed discourse quantities, derived HSS indicators, and latent social states. Directly observed quantities include theme and framing prevalence, keyword importance, semantic relationships, and topic prevalence. These observations can be used to derive higher-level HSS indicators, such as A_t^{HSS}. Such indicators are not assumed to equal latent constructs such as environmental awareness; rather, they provide empirical discourse-level information that may be relevant to evaluating or constraining their temporal representation.

Accordingly, the revised Methods now read:

"The HSS framework distinguishes among directly observed discourse quantities, derived discourse indicators, and latent social constructs. Theme prevalence, framing prevalence, keyword importance, semantic relationships, and topic prevalence are derived directly from the newspaper corpus. Higher-level HSS indicators constructed from these observations may provide empirical information relevant to latent social processes, but they are not interpreted as direct measurements of those processes. This distinction provides a practical pathway for using discourse-derived information to evaluate or potentially constrain social components of sociohydrological models while explicitly retaining the uncertainty associated with indirect inference."

3) Section 4.3.1: The discussion of social-parameter calibration is useful. However, the manuscript does not show how HSS outputs would be used in practice. Please provide a detailed worked example.

Response: We thank the reviewer for this constructive suggestion. We agree that illustrating the practical application of the proposed framework is essential for demonstrating its relevance to sociohydrological modeling. Accordingly, rather than only expanding the conceptual

discussion in Section 4.3.1, we have added a simplified quantitative demonstration showing how an HSS-derived discourse indicator can provide empirical information relevant to a model-based social variable.

Specifically, newspaper articles were classified according to whether they predominantly framed water-related issues in terms of economic development, environmental sustainability, or neither orientation (neutral). From these classifications, we constructed an HSS-derived discourse indicator representing the relative prevalence of environmental-sustainability framing among articles expressing an explicit value orientation:

$$A_t^{HSS} = \frac{N_{ES,t}}{N_{ES,t} + N_{ED,t}}$$

where A_t^{HSS} is the HSS-derived discourse indicator for period t, and $N_{ES,t}$ and $N_{ED,t}$ are the numbers of articles classified as environmental sustainability and economic development, respectively, during that period.

Neutral articles are excluded from the denominator because the HSS indicator is intended to characterize the relative orientation of explicitly value-framed discourse, rather than the overall prevalence of value-oriented newspaper coverage. Because neutral articles constitute an important component of the corpus, however, their prevalence is retained and examined separately:

$$P_{N,t} = \frac{N_{N,t}}{N_t}$$

where $N_{N,t}$ is the number of neutral articles and N_t is the total number of sampled articles during period t. Considering the HSS indicator together with the neutral proportion therefore allows us to distinguish a change in the relative balance between sustainability- and development-oriented framing from a change in the overall prevalence of value-oriented discourse.

Importantly, we do not treat the HSS-derived discourse indicator as a direct measurement of environmental awareness. Rather, it represents an empirically derived discourse signal that may provide information relevant to the latent environmental-awareness state represented in existing sociohydrological models, such as van Emmerik et al. (2014). In this application, the temporal trajectory of the HSS indicator provides an empirical reference for evaluating or potentially constraining the direction and timing of change in a modeled environmental-awareness state. We intentionally do not prescribe or calibrate a specific mathematical relationship between the HSS indicator and the latent environmental-awareness variable because establishing such a relationship would require independent social, behavioral, or institutional observations that are not available in the present study.

This demonstration therefore establishes a practical pathway from observed newspaper discourse to a quantitative HSS indicator and subsequently to a model-relevant social

component, while preserving the distinction between the observable media signal and the underlying latent social construct. A fully coupled sociohydrological model, including estimation of the functional relationship between discourse indicators, social-state variables, and hydrological feedbacks, would require additional hydrological and behavioral observations and is beyond the scope of the present study. The purpose of the present demonstration is instead to show explicitly how an HSS output can be operationalized rather than remaining solely a prospective modeling concept.

Accordingly, the revised Methods now read:

"To demonstrate how an HSS output can provide empirical information relevant to a sociohydrological model component, we constructed a discourse indicator from the manually coded article-framing categories. For each analysis period t, the relative prevalence of environmental-sustainability framing among articles expressing an explicit value orientation was calculated as

$$A_t^{HSS} = \frac{N_{ES,t}}{N_{ES,t} + N_{ED,t}}$$

where $N_{ES,t}$ and $N_{ED,t}$ denote the numbers of articles classified as environmental sustainability and economic development, respectively. The resulting indicator ranges from 0, representing exclusively economic-development framing among value-oriented articles, to 1, representing exclusively environmental-sustainability framing.

Neutral articles were excluded from the denominator because the HSS indicator was designed to characterize the relative orientation of explicitly value-framed discourse rather than the overall prevalence of value-oriented coverage. To retain this information, the prevalence of neutral articles was evaluated separately as

$$P_{N,t} = \frac{N_{N,t}}{N_t}$$

where $N_{N,t}$ is the number of neutral articles and N_t is the total number of sampled articles in period t. Thus, the HSS indicator describes the balance between the two explicit value orientations, whereas the neutral proportion provides complementary information on the overall prevalence of neutral versus explicitly value-oriented discourse.

The HSS indicator is interpreted as an observed discourse-level signal rather than a direct measurement of environmental awareness. We use its temporal trajectory as empirical information potentially relevant to the environmental-awareness state represented in existing sociohydrological models. No direct functional equivalence between the discourse indicator and environmental awareness is assumed in the present study."

The corresponding Results now read:

"The HSS-derived indicator demonstrates a long-term change in the relative orientation of value-framed water discourse. Economic-development framing was more prominent during the earlier decades, whereas environmental-sustainability framing became increasingly prevalent over time, particularly from the 1990s onward. The HSS indicator increased from 0.000 in 1960 to 0.621 in 1990, reaching a peak of 0.917 in 2010, before declining to 0.667 in 2020, indicating a substantial shift toward environmental-sustainability framing over the study period. The neutral proportion was examined concurrently to determine whether changes in the HSS indicator reflected a shift between development- and sustainability-oriented framing within value-laden discourse rather than simply changes in the overall frequency of articles expressing an explicit value orientation.

These results provide a quantitative HSS time series derived directly from the newspaper corpus. Although the HSS indicator should not be interpreted as a direct measure of environmental awareness, its temporal evolution provides an empirical reference for assessing whether a modeled environmental-awareness state exhibits a broadly consistent direction and timing of change."

Section 4.3.1 now further clarifies:

"The present demonstration illustrates how an HSS-derived discourse indicator may inform a social component of a sociohydrological model without assuming equivalence between media discourse and the underlying social state. The HSS indicator is directly derived from observed newspaper framing, whereas environmental awareness is a latent theoretical state representing an underlying social process. The HSS trajectory can therefore serve as an empirical reference for evaluating or constraining the temporal evolution of a modeled awareness state.

For example, if a sociohydrological model represents environmental awareness as increasing in response to changing environmental concerns, the timing and direction of the modeled trajectory can be compared with those independently identified from the HSS indicator. Consistency between the two would provide empirical support for the assumed temporal behavior of the social-state component, whereas substantial disagreement could indicate that its representation or parameterization requires reconsideration. Formal calibration of the relationship between the HSS indicator and environmental awareness would require independent observations of social or behavioral responses and is therefore beyond the scope of the present study."

4) The four week per year sampling strategy requires stronger justification. Could major floods, droughts, pollution events, or policy debates etc have occurred outside these windows? The authors should compare the fixed and random samples separately. They should also test whether the results are sensitive to the chosen weeks.'

Response: We thank the reviewer for this important comment. We agree that the four-week-per-year sampling strategy requires both clearer justification and direct evaluation of its sensitivity.

The sampling design combined two randomly selected consecutive weeks and two fixed hydrologically contrasting periods each year. The random component was intended to provide observations independent of predetermined hydrological timing, whereas the fixed component provided consistent observations during contrasting portions of the annual hydrological cycle. The objective was to characterize broad, long-term changes in newspaper discourse while maintaining the feasibility of detailed manual coding over the 61-year study period, rather than to capture every individual flood, drought, pollution event, or policy debate.

To directly assess sensitivity to the sampling design, we separately analyzed the 319 articles obtained from the fixed-period sampling and the 325 articles obtained from the random-period sampling. Theme and framing distributions were compared between the two subsets to determine which patterns were consistent across sampling strategies and which were more sensitive to the timing of the selected weeks.

Accordingly, Section 2.2 now reads:

"Newspaper articles were sampled using a hybrid design consisting of two randomly selected consecutive weeks and two fixed sampling periods per year. The random component provided observations independent of predetermined hydrological timing, whereas the fixed component provided consistent observations during contrasting portions of the annual hydrological cycle. The objective of this design was to characterize broad, long-term changes in newspaper discourse while maintaining the feasibility of detailed manual coding over the 61-year study period. The final dataset contained 644 articles, including 319 obtained through the fixed-period sampling and 325 through the random-period sampling."

The revised Results now read:

"To evaluate sensitivity to the hybrid sampling design, thematic and framing distributions were compared between the fixed-period sample (n = 319) and the randomly selected sample (n = 325). The results reveal similar distributions across the two sampling designs, with the largest difference observed for Natural Hazards (23.1% in the random sample vs. 33.7% in the fixed-period sample), while Water Policy (25.1% vs. 26.6%), Water for Urban Use (17.0% vs. 17.5%), and Water Quality (15.9% vs. 13.8%) remained comparable. The comparison indicates which long-term patterns are common to both sampling components and which categories, particularly event-sensitive topics such as Natural Hazards, are more strongly affected by the selected sampling periods."

The revised Limitations section now reads:

"Because newspaper coverage was sampled during four weeks of each year, individual floods, droughts, pollution incidents, or policy debates occurring outside the selected periods may not

be represented. The resulting indicators should therefore be interpreted as broad, long-term trajectories of newspaper discourse rather than as a complete record of event-specific media responses. Event-specific causal interpretations are avoided unless the corresponding event is directly represented in the sampled corpus."

5) The orientation of the two newspapers should be discussed. Do they know political, ideological, regional, or institutional alignments? Changes in ownership, readership etc may influence those observed trends.

Response : Thank you for this valuable comment. We agree that the political and institutional orientation of the selected newspapers is important for interpretation.

Both Chosun Ilbo and Dong-A Ilbo are generally regarded as major conservative newspapers in South Korea. Their selection was primarily motivated by the availability of long and relatively continuous archival records over the study period, but their similar orientation limits the extent to which the dataset represents the diversity of Korean media or public opinion.

Accordingly, Section 2.2 now reads:

"Chosun Ilbo and Dong-A Ilbo were selected primarily because both provide extensive and comparatively continuous archival coverage across the 1960–2020 study period. Both newspapers have historically been associated with the conservative segment (Asahina et al., 2024) of the South Korean media landscape. Their use therefore provides temporal consistency but does not capture the full ideological or institutional diversity of Korean media."

The Limitations section now adds:

"Observed trends should consequently be interpreted as changes within two major long-running mainstream newspapers rather than as a representative measure of all Korean media or public opinion. Changes in editorial policy, ownership, readership, and institutional context may also have affected coverage over the six-decade study period."

6) The categories "water policy," "water quality," "water for the environment," and "natural hazards" may overlap. How were articles with multiple themes handled? The authors should provide clearer decision rules. They should also explain whether multiple classifications were allowed.

Response: Thank you for this important comment. We agree that the coding decision rules should be described explicitly.

Articles could contain multiple water-related issues, but multiple classifications were not used in the quantitative analysis. Instead, each article was assigned a single primary theme based on its dominant focus.

Accordingly, Section 2.3 now reads:

"Although individual articles could discuss more than one water-related issue, each article was assigned one primary thematic category for quantitative analysis. The primary theme was determined from (1) the main issue emphasized in the headline and article body, (2) the principal policy, environmental, or societal problem discussed, and (3) the dominant causal or problem framing. Secondary references did not result in additional thematic classifications.

For example, an article concerning river pollution was coded as Water Policy when its dominant emphasis was regulation, institutional action, or governance, whereas it was coded as Water Quality when the primary focus was contamination conditions, pollution severity, or ecological consequences. Articles concerning floods or droughts were classified as Natural Hazards when occurrence, impacts, risk, or disaster response constituted the dominant focus, even when policy measures were also discussed."

7) Please include additional references only when they are directly relevant to the present study. Research on assimilating biophysical remote-sensing observations into hydrological models is not a direct methodological precedent for integrating discourse-derived social indicators. Such references should be included only if the authors establish a clear and substantive connection.

Response: We agree with the reviewer. We have limited methodological references to studies with a direct conceptual or operational relationship to discourse-derived social indicators and sociohydrological model–data integration.

We therefore did not add the suggested remote-sensing assimilation study as a methodological precedent because assimilating a directly observed biophysical variable differs fundamentally from using mediated discourse as an indirect observation of a latent social process.

Accordingly, Section 4.3 now states:

"Because discourse-derived social indicators differ fundamentally from direct physical measurements, their integration into sociohydrological models requires explicit treatment of the observation relationship and associated uncertainty. We therefore draw primarily on studies involving social proxies, collective-memory observations, social-state estimation, and sociohydrological model–data integration when discussing methodological precedents for HSS."

References

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