Community#1 Comments:

1. General comment:

The manuscript presents a novel Human Social Sensing (HSS) framework for quantifying long-term water-related societal discourse using historical newspaper archives. By integrating manual coding with computational text-mining techniques—including TF-IDF, semantic analysis, and topic modeling—the authors derive time-resolved indicators of changes in water-related discourse in South Korea from 1960 to 2020. The results indicate a long-term shift from disaster response and infrastructure development toward water quality, environmental management, and sustainability-oriented narratives. The study provides an interesting interdisciplinary contribution by proposing a structured framework that could potentially support sociohydrological modeling through empirically derived discourse-based proxy variables.

Response: We sincerely thank the reviewer for the thoughtful and constructive evaluation of our manuscript and for recognizing the potential contribution of the HSS framework to sociohydrological research. In response to the specific comments, we have substantially revised the manuscript to clarify the methodological contribution of HSS, distinguish media discourse from latent social constructs, strengthen the sampling and coding analyses, evaluate the robustness of the transition analysis, and provide a quantitative demonstration of how HSS-derived discourse indicators may inform sociohydrological analysis. We have also moderated interpretations that extend beyond what can be supported by the newspaper corpus.

2. Specific comments:

1) This manuscript proposes an interesting Human Social Sensing framework, but its primary methodological novelty should be stated more explicitly. The authors should clearly distinguish how the proposed framework differs from previous studies that have combined manual coding with text mining or topic modeling for environmental and sociohydrological research.

   Response: Thank you for this important comment. We agree that the individual analytical techniques used in this study, including manual coding, TF–IDF, semantic analysis, and topic modeling, are not themselves novel. We have therefore revised the manuscript to avoid implying methodological novelty in these individual techniques.

The primary contribution of HSS lies instead in the structured integration of contextual manual interpretation, scalable computational analysis, temporal transition analysis, and the conversion of these outputs into quantitatively defined discourse indicators that can provide empirical information relevant to latent social processes in sociohydrological systems. We now explicitly distinguish directly observed discourse quantities from higher-level social proxies and clarify that HSS is not proposed as a new text-mining algorithm.

Accordingly, the revised Introduction now reads:

"The methodological contribution of HSS does not lie in introducing a new text-mining algorithm. Manual content analysis, TF–IDF, semantic analysis, and topic modeling have each been applied previously to environmental and social data. Instead, HSS provides an integrated workflow that links contextual human interpretation with scalable computational analysis to transform long-term textual records into reproducible, temporally resolved discourse indicators. In this framework, directly observed quantities such as theme prevalence, framing prevalence, keyword importance, semantic change, and topic prevalence are distinguished from higher-level proxies that may provide empirical information about latent social processes relevant to sociohydrological analysis. This distinction allows historical discourse to be used as observational evidence while avoiding the assumption that media content directly measures public perception or social states."

2) This manuscript repeatedly discusses "public perception," while the analyzed data consist entirely of newspaper articles. Since media discourse does not necessarily represent public opinion, the manuscript should consistently distinguish between media discourse, public discourse, and public perception. Several conclusions should therefore be phrased more cautiously.

Response: Thank you for emphasizing this important conceptual distinction. We fully agree that newspaper articles provide observations of media discourse rather than direct measurements of public perception, attitudes, or societal values.

We have therefore revised the terminology throughout the manuscript. Where the evidence derives solely from newspaper articles, we now use terms such as "newspaper discourse," "media framing," "discourse prevalence," and "discourse-level transition." References to environmental awareness or other latent social constructs are explicitly described as interpretations or proxies rather than directly observed quantities.

Accordingly, the revised Introduction now reads:

"Newspaper archives provide long-term observations of publicly visible media discourse, but they should not be interpreted as direct measurements of public perception. Media content is shaped by editorial decisions, institutional contexts, issue salience, and selective reporting.

Accordingly, this study treats newspaper-derived quantities as indicators of media discourse and framing. Where these indicators are related to latent social constructs such as environmental awareness, the relationship is interpreted as indirect and subject to source, sampling, and representativeness uncertainty."

The revised Results and Discussion likewise use wording such as:

"The observed trajectories indicate a long-term reorientation of water-related newspaper discourse from economic-development framing toward environmental-sustainability framing."

rather than:

"The trajectories indicate a broad societal reorientation in water-related values."

3) The newspaper sampling strategy should be further justified. The use of two randomly selected weeks together with two fixed hydrologically important weeks is reasonable, but the authors should discuss how this sampling approach may influence long-term discourse trends and whether important events occurring outside the selected periods could have been overlooked.

Response: Thank you for this comment. We agree that the sampling strategy requires clearer justification and explicit acknowledgement of its limitations.

The objective of the four-week-per-year design was to characterize broad, long-term changes in newspaper discourse rather than reconstruct every individual hydrological event or short-term media response. Two randomly selected consecutive weeks were used to provide temporal representation independent of predetermined hydrological conditions, whereas two fixed periods were included to provide consistent observations during contrasting portions of the annual hydrological cycle.

We also separately evaluated the fixed-period and random-period components to examine whether the major conclusions depend strongly on the sampling approach. The revised manuscript now explicitly acknowledges that floods, droughts, pollution events, or policy debates occurring outside the sampled periods may not be represented.

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 that were not conditioned on 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. It was not intended to provide a complete census of individual hydrological events or media responses. The final dataset contained 644 articles, including 319 articles obtained through the fixed-period sampling and 325 through the random-period sampling."

The revised Results now additionally state:

"To examine sensitivity to the sampling design, thematic and framing distributions were evaluated separately for the fixed-period and randomly selected samples. 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 sampled periods may not be represented. The resulting indicators should therefore be interpreted as broad, long-term trajectories of newspaper discourse rather than as a comprehensive record of event-specific responses. Event-level causal interpretations are avoided unless the event is directly represented in the sampled corpus."

4) Manual coding plays a central role in the framework, yet no formal intercoder reliability statistics are reported. Although disagreements were resolved through a third coder, the manuscript would be strengthened by reporting metrics such as Cohen's κ or Krippendorff's α to demonstrate the consistency and reproducibility of the manual classifications.

Response: Thank you for this important suggestion. We agree that the intercoder reliability assessment should have been explicitly reported. Intercoder reliability was evaluated from the independent classifications made by the two coders prior to reconciliation. The initial agreement was 88.0% for thematic classification, corresponding to Cohen's $\kappa = 0.850$, and 83.1% for tonal classification, corresponding to $\kappa = 0.726$. Remaining disagreements were subsequently resolved by a third independent coder.

We have now added these statistics as well as the coding and reconciliation procedures to the Methods. We have also removed the previous implication that formal intercoder reliability assessment is only a recommendation for future applications.

Accordingly, Section 2.3 now reads:

"Newspaper articles were independently coded by two graduate-level researchers with backgrounds in water and environmental studies. Intercoder reliability was assessed from the independent classifications before reconciliation. Initial agreement was 88.0% for thematic classification (Cohen's $\kappa = 0.850$) and 83.1% for tonal classification ($\kappa = 0.726$), indicating substantial to strong agreement between the two coders. Cases in which the coders disagreed were subsequently reviewed and resolved by a third independent coder. The reconciled classifications were used in the subsequent quantitative analyses."

5) The authors are recommended to cite recent work demonstrating the assimilation of remotely sensed environmental information into integrated hydrological models. In particular, Zafarmomen, N., Alizadeh, H., Bayat, M., Ehtiat, M., and Moradkhani, H.: Assimilation of Sentinel-based leaf area index for modeling surface–ground water interactions in irrigation districts, Water Resources Research, 60(10), e2023WR036080, 2024, is highly relevant. Although that study focuses on satellite-based vegetation assimilation rather than discourse analysis, it similarly addresses the incorporation of externally derived proxy information into hydrological modeling to improve representation of coupled human–water processes

Response: We thank the reviewer for this thoughtful recommendation and for drawing our attention to the broader importance of incorporating independently derived observational information into model-based hydrological analysis. We carefully considered the suggested study by Zafarmomen et al. (2024) and agree that it provides a useful example of how externally derived observations can be incorporated into a hydrological modeling framework to better constrain system representation.

However, after further consideration, we decided not to include this study as a methodological reference in the revised manuscript because the observation problem addressed there is substantially different from that addressed by the present study. Zafarmomen et al. (2024) assimilated remotely sensed leaf area index, which represents a physically based biophysical observation that can be directly related to modeled system states and processes. In contrast, HSS derives quantitative indicators from newspaper discourse. These indicators are mediated observations influenced by editorial selection, source orientation, sampling, and historical context and therefore cannot be treated as direct observations of latent social processes such as environmental awareness or collective memory.

We agree with the broader conceptual point raised by the reviewer that independently derived observations can improve the empirical basis of model representations. However, we believe that presenting physical remote-sensing assimilation as a methodological precedent for HSS could blur an important distinction between directly observed biophysical states and indirectly inferred social states. We have therefore strengthened the revised manuscript using literature that more directly addresses social observations and proxies, collective memory, latent social-state representation, and model–data integration in sociohydrology, including studies such as Sawada and Hanazaki (2020), Song et al. (2021), van Emmerik et al. (2014), and Roobavannan et al. (2018). These studies provide a closer methodological foundation for explaining how HSS-derived discourse indicators may inform otherwise difficult-to-observe social components of coupled human–water systems. The revised manuscript also now makes the distinction between an observed discourse indicator and the latent social construct it may help inform much more explicit.

Accordingly, the revised Discussion now reads:

“The use of HSS indicators in sociohydrological modeling requires an explicit distinction between observable discourse signals and the latent social processes that these signals may inform. Unlike hydrological or biophysical observations, which can often be directly associated with physical model states, HSS-derived indicators represent mediated observations of media discourse. They therefore should not be equated directly with environmental awareness, collective memory, risk perception, or other latent social states.

Instead, HSS indicators can be treated as empirical discourse proxies that contain information potentially relevant to otherwise difficult-to-observe social processes. For example, temporal changes in hazard-related discourse may provide information relevant to collective memory, whereas changes in environmental-sustainability framing may provide information relevant to a latent environmental-awareness state. Their use in sociohydrological analysis therefore requires explicit consideration of the conceptual and empirical relationship between the observed discourse signal and the underlying social construct, together with the uncertainty introduced by sampling, source selection, editorial framing, and representativeness.

This interpretation is consistent with sociohydrological studies that use empirical social information to constrain or evaluate human-system components. Sawada and Hanazaki (2020), for example, demonstrated the value of model–data integration for representing human–flood interactions, while Song et al. (2021) examined the representation of collective memory in sociohydrological modeling. Likewise, van Emmerik et al. (2014) and Roobavannan et al. (2018) demonstrated the importance of environmental awareness, norms, and values in the dynamic representation of coupled human–water systems. Building on this literature, HSS provides a complementary observational pathway by transforming long-term discourse records into temporally resolved indicators that may help constrain or evaluate latent social-state representations.

Because these indicators are derived from media discourse rather than direct behavioral observations, their use must account for uncertainty associated with sampling, coding, editorial selection, newspaper orientation, and the broader relationship between media discourse and societal response. HSS should therefore be viewed as a source of empirical information about latent social dynamics rather than as a direct measurement of those dynamics.”

6) The transition-theory analysis is interesting, but the identified transition stages rely on nonlinear regression and derivative analysis. The authors should clarify the uncertainty associated with the estimated transition years and discuss whether alternative regression models would produce similar transition boundaries.

Response: Thank you for this important comment. We agree that the sensitivity of the estimated transition periods to the assumed nonlinear model should be evaluated and that the resulting transition years should not be interpreted as exact calendar-year thresholds.

We therefore fitted three alternative S-shaped transition functions, Gompertz, Richards, and Bass, in addition to the original logistic formulation and applied the same derivative-based criteria to each fitted trajectory. This analysis evaluates model-form sensitivity, rather than statistical confidence intervals around individual transition dates.

The estimated transition boundaries were broadly consistent among the alternative models. The take-off boundary varied by approximately 1 year, the acceleration center by approximately 3 years, and the late-stage deceleration or stabilization candidate by approximately 5 years. We have therefore revised the manuscript to describe the identified transition times as approximate periods and to distinguish model-form sensitivity from statistical uncertainty.

We have also revised the interpretation of the final derivative feature. Because the observed trajectory does not demonstrate that a stable endpoint had been reached by 2020, this feature is now described as a late-stage deceleration or stabilization candidate, rather than evidence that stabilization actually occurred.

Accordingly, Section 2.5 now reads:

"Because derivative-based transition boundaries may depend on the assumed nonlinear functional form, robustness was evaluated using logistic, Gompertz, Richards, and Bass models. The same derivative-based criteria were applied to each fitted trajectory. Differences among the resulting boundaries were interpreted as model-form sensitivity rather than statistical confidence intervals. Accordingly, identified transition years are interpreted as approximate temporal periods rather than exact calendar-year thresholds."

The revised Results now read:

"The estimated transition boundaries were broadly consistent across the four S-shaped models. The take-off boundary varied by approximately 1 year, the acceleration center by approximately 3 years, and the late-stage deceleration or stabilization candidate by approximately 5 years. This consistency indicates that the broad transition structure is not an artifact of a single nonlinear formulation. These ranges represent sensitivity to model choice rather than statistical confidence intervals. The final derivative feature is therefore interpreted as a potential deceleration or stabilization boundary rather than evidence that the discourse transition had reached a stable endpoint by 2020."

Boundary	Logistic	Gompertz	Richards	Bass	Variation
Take-off start (2nd deriv peak)	1973	1972	1972	1973	1 yr
Acceleration center (1st deriv peak)	1986	1983	1983	1986	3 yr
Stabilization candidate (2nd deriv peak)	1999	1994	1994	1999	5 yr

7) The discussion on integrating HSS into sociohydrological models is valuable but remains largely conceptual. The manuscript would benefit from at least one practical demonstration or simplified case showing how one of the proposed discourse indicators (e.g., sustainability framing or hazard memory) could be incorporated into an existing sociohydrological model parameter or state variable.

Response: We thank the reviewer for highlighting this important point. We agree that the practical use of HSS-derived indicators in sociohydrological modeling should be demonstrated more explicitly rather than discussed only as a potential application.

To address this concern, we have added a simplified quantitative demonstration using the framing categories already generated through manual coding. Specifically, we construct an HSS-derived 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 $N_{ES,t}$ and $N_{ED,t}$ denote the numbers of environmental-sustainability- and economic-development-framed articles, respectively, during period t. The indicator ranges from 0, representing exclusively economic-development framing among value-oriented articles, to 1, representing exclusively environmental-sustainability framing.

Neutral articles are excluded from the denominator because A_t^{HSS} 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 represent an important component of the corpus, however, their prevalence is retained and 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 during period t.

Importantly, A_t^{HSS} is not interpreted as a direct measurement of environmental awareness. Rather, it is an empirically derived discourse indicator whose temporal trajectory may provide information relevant to the latent environmental-awareness state represented in existing sociohydrological models, such as van Emmerik et al. (2014). The demonstration therefore shows how observed discourse can be converted into a quantitative HSS output that provides an empirical temporal reference for evaluating or potentially constraining a model-relevant social variable.

We do not prescribe or calibrate a specific mathematical relationship between A_t^{HSS} and latent environmental awareness in the present study. Establishing such a relationship would require independent social, behavioral, or institutional observations beyond the present dataset. The purpose of this demonstration is instead to establish an explicit operational pathway from observed newspaper discourse to a quantitative HSS indicator and subsequently to a social component of a sociohydrological model.

Accordingly, the revised Methods now read:

"To demonstrate how an HSS output can provide empirical information relevant to a sociohydrological model component, we constructed an indicator from the manually coded 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 A_t^{HSS} characterizes the relative orientation of explicitly value-framed discourse rather than the overall prevalence of value-oriented coverage. The prevalence of neutral articles was therefore 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 during period t.

A_t^{HSS} is interpreted as an observed discourse-level indicator rather than a direct measurement of environmental awareness. Its temporal trajectory is used 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."

References

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