Responses to Reviewer:

[Authors' response] We would like to sincerely thank the reviewer for his/her supporting and for taking the time to review our manuscript. Your good suggestions have increased our papers quality. thank you very much!

To Reviewer 3:

While the manuscript addresses an important challenge in groundwater contamination source identification, its novelty is limited. The core contribution lies in introducing the Artificial Hummingbird Algorithm (AHA) into a simulation-optimization framework, which is not a fundamentally new algorithm nor specifically tailored to groundwater inverse problems. Furthermore, many techniques used—BPNN, Kriging, PSO, SSA—are already well-established in the literature.

Moreover, the reported simulation results show extremely high precision (e.g., $R^2 > 0.999$, MRE < 2%), which may suggest possible overfitting or idealized experimental setups. The study lacks rigorous testing of generalization under realistic uncertainty scenarios, such as sparse observations, complex geological heterogeneity, or parameter noise. Without such assessments, the practical robustness and transferability of the proposed framework remain questionable.

The paper would benefit from a deeper methodological insight into why AHA performs better in this specific problem context, rather than merely benchmarking its numerical results. The current framing gives the impression of "algorithm replacement" without substantive theoretical or application-driven innovation.

[Authors' response] We are grateful to the reviewer for your insightful evaluations and valuable comments, which have greatly inspired us. We fully understand your concerns regarding the innovativeness of the methods, the rationality of the algorithm selection, and the authenticity of the experimental design. Here, we would like to provide a systematic explanation of the following points to further clarify the structural design, academic contributions, and application applicability of this study, thereby addressing the core issues raised by the reviewer.

This study does not aim to propose a novel algorithm in a strict sense, but rather to construct an inversion framework specifically tailored to the complex characteristics of groundwater contamination source identification. The source identification problem typically requires simultaneous estimation of pollutant sources, aquifer hydraulic parameters, and boundary conditions, resulting in a high-dimensional, ill-posed, and strongly coupled system. Many existing studies address only one category of these parameters, or rely on idealized assumptions (e.g., known boundaries or fixed parameter fields) to simplify the inversion process, limiting their applicability to real-world field conditions.

To address this challenge, we propose a hybrid framework that couples surrogate modeling and intelligent optimization, enabling efficient and coordinated inversion of multiple unknowns in complex pollution scenarios while maintaining computational tractability. The inversion task essentially constitutes a non-convex, high-dimensional, and tightly coupled optimization problem, where the objective function is typically multi-modal and irregular due to the simultaneous estimation of pollution source characteristics, permeability coefficients, and boundary conditions. These features often lead traditional metaheuristic algorithms (e.g., PSO, SSA) to premature convergence or low search efficiency.

In contrast, the AHA leverages a bio-inspired directional foraging strategy, integrating three complementary movement patterns—axial, rotational, and omnidirectional search—to dynamically balance global exploration and local exploitation. Specifically, AHA mitigates early convergence through mode switching, maintains solution diversity in the early stage, and enhances convergence efficiency in promising regions during later stages. This mechanism is particularly crucial in our framework, as the BPNN surrogate inevitably introduces approximation errors. AHA's adaptive update strategy helps offset fluctuations caused by these errors, thus ensuring robustness and stability of the inversion process. The combination of BPNN and AHA is not arbitrary but is rooted in the complementarity of their mechanisms and their alignment with the problem's structure.

For case design, two representative and challenging contamination scenarios were selected. The first involves temporally varying point-source pollution, often observed in industrial accidents and accidental spills. The second involves spatially diffuse non-point source pollution, commonly associated with agricultural runoff and leaching sites. Both scenarios feature unknown pollution source parameters, uncertain aquifer properties, and complex boundary conditions. These synthetic cases are not intended to validate the framework under idealized assumptions, but rather to serve as a controlled and structurally representative testbed for evaluating the performance of different surrogate–optimizer combinations under identical problem structures.

We acknowledge the reviewer' concerns regarding the reported high prediction accuracy (e.g., $R^2 > 0.999$, MRE < 2%) in the simulation results. While these test cases are critical for verifying model behavior and enabling comparative analysis, we agree that they cannot fully represent the complexities of real-world environments. In the revised manuscript, we will explicitly acknowledge this limitation and expand our discussion on how the framework can be adapted and evaluated under more realistic conditions, including sparse monitoring networks, parameter uncertainty, and heterogeneous aquifer settings. We have already begun incorporating such tests into our ongoing work and have outlined this as a key direction for future development.

Lastly, we wish to clarify that although our study does not involve algorithmic invention per se, its primary contribution lies in application innovation and modular adaptability. We present a framework that not only achieves high performance under controlled conditions but is also sufficiently flexible to be extended to various field-scale groundwater inverse problems, including both point and non-point source contamination scenarios. Such an integrated and application-oriented modeling approach—particularly one that is computationally efficient and compatible with limited field data—is of direct relevance to both environmental practitioners and researchers. We hope these clarifications and revisions more accurately convey the intention, applicability, and potential of our work.