REVIEWER1:

One small comment: the hypothesis (lines 111-113) says essentially "our methods will work" or "our methods will be useful." As such, I think it's somewhat contrived and untestable.

Authors response:

Thanks for this comment, we made a minor modification to the sentence to better reflect that the hypothesis is not that the methods “work”, but that integrating microbial community data with more conventional hydrogeochemical and isotopic tracers provides additional, independent information that improves the interpretation of groundwater origin, mixing, and connectivity. See lines 75-77.

REVIEWER2:

General assessment

I appreciate the authors’ efforts in revising the manuscript. Several aspects have improved, in particular the clarification of Section 3.4 and the addition of flow directions to Figure 1. However, in my view, several major concerns remain insufficiently addressed, most importantly the lack of a clear research question and the limited integration between the different tracer datasets. These issues continue to affect the overall structure of the manuscript and the interpretation of the results.

Major concerns

1. Research question

This point remains unresolved. At present, the research question is still not clear. The only sentence in the introduction that appears to state a possible research objective (L32–35) is too weak to serve as a proper research question.

More generally, the introduction does not build toward a clear scientific objective. It provides very little general background and moves rapidly to the statement mentioned above. The subsequent paragraphs then introduce the different tracers used in the study one by one, often with theoretical explanations of how each tracer works. This structure is not appropriate for an introduction and would be more suitable, in a much shorter form, within the methodology section.

In a scientific paper, the introduction should develop from general background toward a clearly identified knowledge gap, which then motivates the research question and the chosen methodology.

Here, this step is missing. In particular, no clear knowledge gap is articulated, making it difficult to understand what specific problem the study is addressing or why this combination of tracers is required.

I therefore strongly suggest rewriting the introduction so that it explicitly identifies a knowledge gap and builds logically toward a well-defined research question. One possible approach would be to briefly review how tracers are currently used to investigate groundwater systems (from an application perspective rather than a theoretical one), and then explain why this approach is insufficient in the present hydrogeological context. This would provide a clear rationale for the study.

This issue also affects the discussion. At present, the discussion does not follow a clear line toward answering a defined question and instead largely describes the results in more detail. In its current form, the manuscript reads more like a scientific report than a research paper.

Authors response:

We thank the reviewer for thorough inspection of the manuscript. We have substantially revised the introduction and parts of discussion to improve its structure and clarity. Specifically, we now explicitly identify the knowledge gap related to unresolved groundwater connectivity and mixing processes in complex buried valley aquifers (see revised manuscript lines 43-47). The Introduction has been restructured to follow a clearer progression from general background to this knowledge gap, which directly motivates the study.

We have also reformulated the research objective into a clearly stated research question, presented at the end of the Introduction, l. 71-75. Additionally, detailed descriptions of individual tracers have been reduced and reframed to avoid a method-like presentation and instead focus on their relevance to the research problem (l.48-59). We hope that these changes in the manuscript now clarify the scientific motivation and better align the manuscript to research article style.

The revised discussion is now structured around the research question, descriptive elements have been reduced, and synthesis has been introduced to highlight the key insights gained from combining hydrogeochemical, isotopic, and microbial data. We demonstrate the added value of microbial community analysis in resolving ambiguities in classical tracer interpretations and show how microbial communities support the interpretations made with more classical tracers.

2 & 3. Tracer interpretation and methodological transparency

These points have been addressed substantially better in the revised version. In particular, the rewritten Section 3.4 is much clearer and improves the manuscript considerably, although a few refinements are still needed.

It remains remarkable that these deep waters contain relatively high dissolved oxygen concentrations, together with probably up to 5% CO2. I would encourage the authors to discuss the origin of the CO2 in more detail. For example:

• Could the CO2 be linked stoichiometrically to O2 consumption or production processes?

• If the oxygen is not due to contamination, does it provide information about recharge or (fast) infiltration conditions?

Response:

We have now clarified the depth interval of Kurikka deep valley system in the Introduction and added this also to Site description, as it might have been too ambiguously stated in the previous version. Thus, these are not as deep as some aquifers as in for example Central Europe or other parts of the world, and thus, the dissolved oxygen concentrations (here mostly below 5mg/l, see table 2) of the groundwaters are not particularly surprising.

On the specific questions, we didn't see the discussion of the origin of CO2 in the system to fit our research question and specific aims so this was dismissed. Similarly, although O2 might give some insight into infiltration conditions, we didn't see this discussion necessary for the manuscript.

4. Integration between datasets

This remains a major concern. The connection between the different tracer datasets and the microbiological data is still not sufficiently developed. However, this issue may partly stem from the lack of a clear research question. A better-defined objective would likely also provide a stronger basis for integrating the different tracers and discussing how they complement one another.

Response:

We have added linking and concluding statements in the discussion that explicitly connect the individual observations to the broader hydrogeological interpretation and the research question. Manuscript now emphasizes how the combined multitracer and microbial approach improves the conceptual understanding of groundwater connectivity and biogeochemical processes. We hope that the discussion now reads more as a clear and coherent interpretation rather than a reiteration of results.

5. Site characterization

This point has been addressed satisfactorily. The addition of flow directions to Figure 1 is useful and improves the hydrogeological context.

One minor comment remains: Figure 1 was modified, but the legend does not appear to have been updated consistently. Several legend elements still seem to refer to the previous version of the figure.

Response:

We are happy that the revised figure 1 now does it's job. The figure legend has been modified.

6. Figures and tables

I remain concerned that seven main figures and four main tables are too much for the main manuscript. Some of this material could likely be moved to the Supplementary Information.

For example, Table 1 could probably be moved out of the main text.

Figure 5 could also be shortened. At present, both the bar plots and the heatmaps convey largely similar information, but at different taxonomic levels: the bar plots at phylum level and the heatmaps at order level. This could likely be streamlined, or the heatmaps could be moved to the Supplementary Information.

This point also relates back to the lack of a clear research question. Without a defined question guiding the paper, the figures seem to serve mainly to display all measured results rather than to support a focused interpretation. Figures should help answer the research question and address the identified knowledge gap. Since this is currently missing, it is difficult to judge which figures are truly essential.

Response:

We have now moved one figure to supplementary data (see supplementary figure 2) but would like to argue that all the other figures and tables have their place in the manuscript.

Table 1 complements figure 1 in the area description and serves as an introduction of the sampling sites.

Table 2 and 3, and figure 3 describe the field measurements and isotopic data that are used in interpretation of the main results of the manuscript.

Figure 2. combines the data from major element analysis and shows the geochemical differences of the water samples.

Table 4 gives the results of the noble gas analyses and provides the data for the interpretation of these for the figure 4.

Figure 5. combines microbial diversity and community structure profiles of the samples. Manuscript discusses diversity in relation to the retention times of the different groundwaters studied, therefore the Shannon diversity is shown in the figure. Microbial community structure is typically shown in coarser phylum-level to provide a broad overview of dominant microbial groups across environments and large-scale differences can be identified immediately. The more detailed level (here the heatmaps showing most abundant community members in order level) allows identification of ecologically and geochemically relevant microbial groups (e.g., sulphate reducers, fermenters, iron-cyclers discussed in the manuscript) that cannot be distinguished at phylum level. The heatmap format also highlights relative abundance patterns across samples showing site-to-site specific microbial fingerprint.

7. Discussion

This concern is, in my opinion, largely encompassed by the comments above. The descriptive character of the discussion is closely tied to the absence of a strong research question and a corresponding conceptual framework.

Response:

As stated above, discussion has now been partly rewritten to improve its focus and interpretative depth. The revised discussion now synthesises hydrogeochemisty and microbiology results in more holistic way and shows how the results contribute to the understanding groundwater origin, residence times connectivity and mixing patterns.

Minor comments

I am not sure how useful these minor comments are at this stage, given that the manuscript still appears to require major revision. I would strongly encourage the authors to focus first on the major concerns above.

• L106–107: “The aim of this study was” — it is not clear whether this refers to the cited study or to the present manuscript. More generally, present tense should be used in the introduction.

-This has been modified and introduction is now written in present tense.

• L275: use a non-breaking space before ◦C.

-Corrected

• Table 2: it is unclear what the reported depth represents in the clustering.

-It shows the relative Euclidean dissimilary between the samples. This information has now been added to the figure legend.

• L336: the last sentence should be rewritten.

-The sentence is corrected.

• L345–346: the sentence should also be rewritten for clarity.

-grammar corrected

• L352–353: it would help to add one short sentence explaining why large Ne uncertainties make age calculations more difficult.

-minor modifications made for explanation

• L356–358: this is a good argument, but it is only valid if the CFC and noble gas analyses were performed on the same physical sample container. If different containers were used, for example sample A for CFCs and sample B for noble gases, the absence of contamination in sample A does not exclude contamination in sample B.

-we agree, and it is true that different techniques and containers were used for collection of noble gases and CFCs.

• Figure 4: the figure is currently rather difficult to read, especially the point labels. Please improve readability.

-Figure 4 has now been updated with zoomed-in figure inside the plot

• L433–437: this is not a very useful paragraph with which to open the discussion.

-we argue that it has it's place here, but we can remove it if absolutely necessary.

• L443–444: please be more precise. Lower or higher pH may indicate longer interactions; the wording in terms of "differences" is unclear.

This has been reformulated in lines 415-417

• L476: "which corresponds to R56, but also to the rest of the samples here" —this effectively means all samples. Please reformulate.

-sentence has been edited for clarity, l. 448-454

• L486–487: sentence unclear, please reformulate.

-Sentence has been reformulated, see l. 462-463

General writing and notation

Please be consistent with abbreviations and chemical notation. Some abbreviations are introduced but then not used consistently. For example, tritium is introduced as 3H, but

the text later reverts to spelling out “tritium”. The chemical notation should also be standardized throughout the manuscript, for example using 3H instead of “3H”.

-These have now been corrected through the manuscript, however we prefer beginning the sentences with Tritium rather than ^{3}He.

Recommendation

In my view, the manuscript has improved in some respects, but the central issue remains the absence of a clearly formulated research question and the resulting lack of a coherent interpretative framework. This continues to affect the introduction, the discussion, the integration of datasets, and the selection of figures and tables. I therefore consider that major revision is still required.