Reviewer Report

Summary

The manuscript presents a multi-tracer investigation of a buried-valley aquifer system in Kurikka (Finland), combining hydrochemistry, environmental isotopes, noble-gas-based age tracers, and microbial community analyses across several wells. The overall aim appears to be a characterization of the multi-layered aquifer using complementary methods (i.e., combining tracer hydrology and microbiology).

Recent studies have already demonstrated the potential of combining microbiological and environmental tracers to examine groundwater systems. Situating the study more explicitly within this existing frame of work would help contextualize the approach and clarify its contribution.

Major Concerns

1. Lack of research question, hypothesis, and conceptual focus

The manuscript does not articulate a research question or hypothesis, nor does it explain why this specific suite of tracers and microbiological approaches is required to address a defined problem. As a result, the study reads primarily as a catalogue of measurements, and the discussion remains largely descriptive. Without a defined scientific objective, it is difficult to evaluate the relevance or interpretation of the results.

2. Insufficient treatment and interpretation of noble gas, CFC/SF_6, and $^3H/^3He$ data

The tracer dataset contains internal inconsistencies that remain unexplained:

- Ne concentrations exceed air-saturated water (ASW) values by 121–427%, which is far above typical excess-air ranges expected for such aquifers.
- Some CFC and SF_6 values also exceed ASW by large margins.
- Dissolved O_2 values reach several hundred percent of ASW (23–401%), including values incompatible with waters sampled at depths up to 160 m.
- Tritium values are inconsistently reported, and negative $^3He^*$ values appear to have been omitted without comment. When applying the unfractionated air (UA) model to the published data, similar $^3H/^3He$ results can be reproduced; however, this approach also yields negative $^3He^*$ values, which seem to have been excluded from the table without explanation.
- There is no indication how terrigenic and tritiogenic helium concentrations were calculated, which makes them difficult to be interpreted.

Such large oversaturations in O_2, Ne, CFC, and SF_6 could stem from sampling artefacts, air contamination, or analytical issues. If real, they require detailed mechanistic discussion. As presented, the tracer dataset cannot be reliably interpreted.

3. Lack of methodological transparency

Several essential methodological elements are missing, preventing reproducibility. Examples include:

- There is no indication of how terrigenic and tritiogenic helium concentrations were converted into age, which makes their interpretation difficult.
- No description of how terrigenic ^{4}He was separated from atmospheric components.
- No justification for omitting negative ^{3}He*-derived ages.
- Missing operational details such as pumping setup, flow rates, sample handling, and field conditions.

These elements are critical for evaluating reliability, and the present level of detail is insufficient.

4. Insufficient integration between microbiological and tracer datasets

The manuscript reports microbial and hydrochemical results but does not clearly connect them. The potential value of combining microbial community structure with isotopic and noble gas tracers is not demonstrated. The discussion does not link redox conditions, residence times, mixing processes, or flow systems to microbial patterns. As a result, the combined dataset does not produce a unified hydrogeological interpretation.

5. Limited site characterization

The hydrogeological context of the study area is not described in sufficient detail. Flow directions, stratigraphy, connectivity between aquifers, and the position of the unconsolidated aquifer relative to the sampled wells are not clearly presented. This makes it difficult to interpret the tracer results or understand how the sampling locations relate to flow paths.

6. Figures and tables require substantial revision

Several figures and tables are not sufficiently clear, contain redundant information, or do not contribute meaningfully to the interpretation. A reduction in the number of figures, focusing on more integrative and hydrologically relevant visualizations, would strengthen the manuscript.

Suggested improvements include:

- Combined tracer–isotope heatmaps linked with microbial community data.
- A ^{3}He/^{4}He vs. Ne/^{4}He diagram including ASW, air, crustal, and other endmembers.
- Clearer representation of aquifer geometry and flow systems.

There is also interpretive potential in several existing figures. For example, the patterns in the current Figure 5 showing the strontium isotopes data may indicate mixing trends or groundwater evolution relevant to groundwater flow.

Table 4 contains missing uncertainties, inconsistent reporting, and unexplained omissions. If replicates were taken, standard deviations should be reported consistently.

7. Interpretation remains descriptive

Without a guiding question or conceptual framework, the manuscript does not progress beyond description. A hydrogeological model relating the measured variables to flow, recharge, mixing, or redox evolution would greatly improve interpretive strength. Some figures and questions are added here which might stimulate some interesting scientific discussion.

Additional suggestion: Given the complexity of noble gas and age-tracer interpretation, and the inconsistencies identified in the dataset, it may be beneficial for the authors to consult with a tracer hydrology specialist to ensure that sampling, modelling, and interpretation follow established practices.

Recommendation

Given the absence of a research question, inconsistencies in key tracer datasets, limited methodological transparency, and lack of integrated interpretation, I cannot recommend the manuscript for publication in its current form. Addressing these concerns would require major restructuring, re-analysis of the tracer datasets, improved methodological documentation, and development of a focused conceptual framework.

Figures

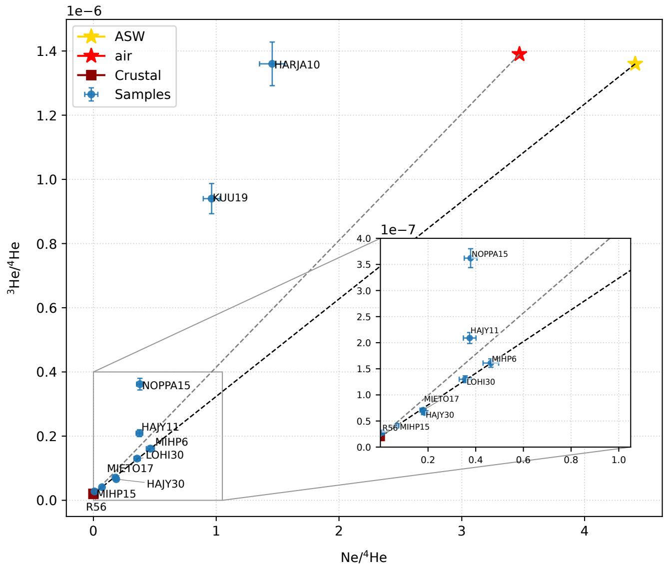

Figure 1: Illustrative example of a $^3He/^4He$ vs. $Ne/^4He$ plot that could support interpretation of water origins. Provided solely to clarify the suggestion in the review.

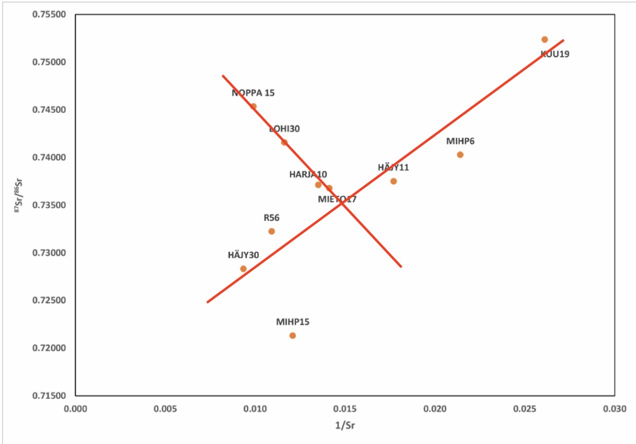

Figure 2: Illustrative reproduction of the manuscript's Figure 5 to highlight possible mixing relationships. Provided for review purposes only.

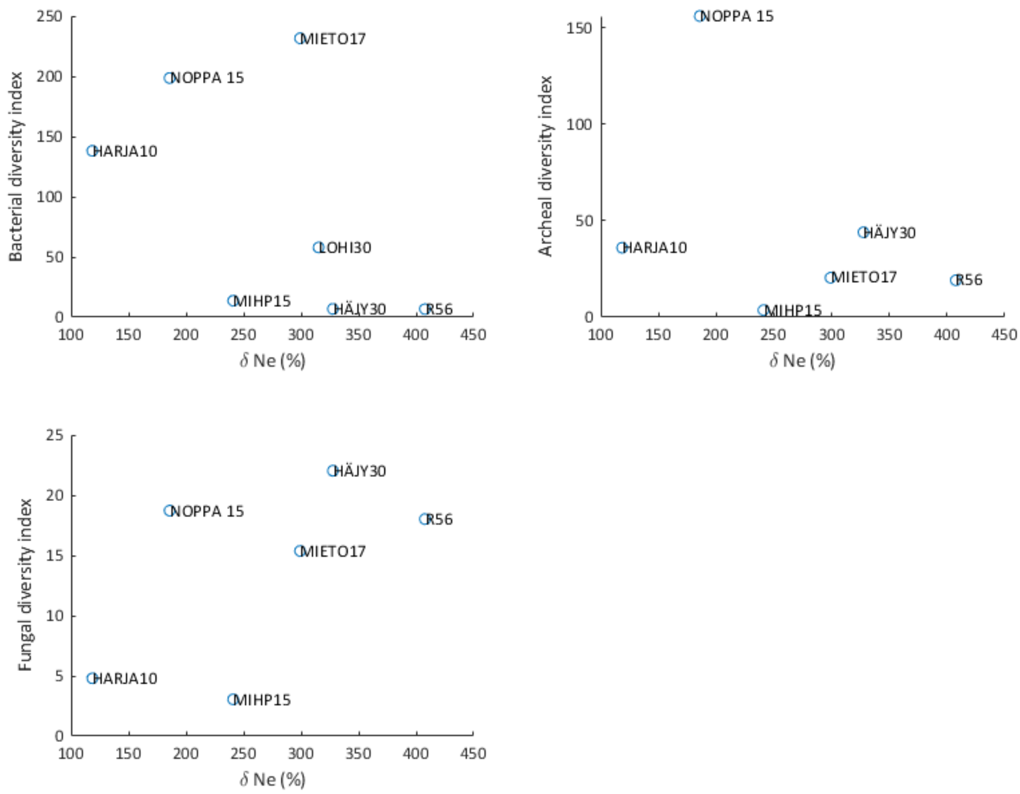

Figure 3: Correlations between excess Ne and various microbial metrics highlight additional questions arising from the dataset. Although the groundwater should be anoxic at the reported depths, the samples contain substantial dissolved oxygen, while the archaeal and bacterial communities are characteristic of strictly anoxic environments. These contrasting patterns raise the possibility of air contamination. The apparent association between excess Ne and fungal diversity is also notable. While anaerobic fungi are known from certain specialised environments, their occurrence remains uncommon. Such observations therefore warrant careful interpretation in light of the unusually high gas oversaturation reported.