

High-resolution monitoring of the Günz River: Assessing water quality risks for managed aquifer recharge

Revision letter

Lea Augustin and Thomas Baumann

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Dear Uwe Ulbrich,

Thank you for giving us the opportunity to resubmit our revised manuscript with minor revisions to NHESS. Special thanks also for your time and effort in evaluating the changes. We adjusted the manuscript as indicated in the individual answers to the three reviews. Please find the referees' comments in black font and our answers and related changes in blue. At the end, all manuscript corrections are listed.

Best regards,
Lea Augustin and Thomas Baumann

Referee #1

This manuscript presents a comprehensive, well-executed study on high-resolution monitoring of the Günz River in Bavaria, Germany, aimed at evaluating its suitability for Managed Aquifer Recharge (MAR). The combination of watershed risk screening, continuous monitoring using a custom-built kit, and detailed chemical analysis is innovative and well documented. The paper is timely, relevant, and provides new insights into real-time water quality assessment and risk-based management for MAR.

The methodology is robust and transparent. All instruments, calibration methods, and sampling protocols are clearly described. The description of data, methods, and analytical approaches is sufficiently detailed to ensure reproducibility. The availability of code and data as well as the plan for building the monitoring station is commendable.

We sincerely thank the reviewer for the thoughtful, constructive feedback and for the positive evaluation of our manuscript. In the following, we respond to each of the reviewer's suggestions in detail. We hope that these additions strengthen the manuscript and address the reviewer's insightful comments.

Suggestions:

1. While the transferability of methods to other rural watersheds is noted, it would help to more explicitly compare the Günz catchment characteristics with other European or international contexts.

We agree that a direct comparison of the Günz watershed to other watersheds would provide easy access to the suitability of catchments for this type of MAR. In general, we have to distinguish between the transferability of the methodology and the applicability of the site-specific results. The methodology itself is site-independent and can be applied to regions with different hydrological and hydrogeological conditions. Here, we consider the rural-urban distinction and the size of the watershed to be the primary factors influencing transferability. We have clarified this more explicitly in the corresponding discussion section to support a broader comparison with other catchments (line 524-531). However, site-specific results rely on actual measurements and field observations, so direct, quantitative comparisons are limited unless similar data are available.

2. The abbreviation MAR appears in the abstract without introduction (which follows in the intro). Better state the full term in the abstract.

We agree and have revised the abstract accordingly (line 16).

3. Spaces before % seem uncommon to me but are apparently sometimes used in articles. I would not use a space before % and I think it's rather international norm to do so.

Thank you for pointing this out. We have revised the manuscript to remove spaces before all % symbols (line 26, 120-122, 127,128, 245, 260, 352, 359).

4. In the conclusion "MAR with river water is -essential- to adapt to the imbalance of the landscape water regime" seems to be a bit if an overreach. While MAR is valuable, calling it essential suggests it's the only viable adaptation, which might not be universally agreed upon.

We appreciate this observation and have adjusted the sentence to "MAR with river water presents a highly valuable strategy to adapt to the imbalance of the landscape water regime" (line 546).

5. The conclusion could mention how this work supports future MAR implementations or research. Future work could explore microbiological risks and the applicability of this framework in more urbanized regions.

Thank you for this suggestion. We have added a sentence in the conclusion pointing to these potential next steps (line 566-568).

Recommendation: Minor Revisions

The paper is well-suited for publication in NHESS after addressing the minor suggestions above. It provides a valuable case study and a replicable framework for river monitoring in the context of MAR.

Referee #2

The introduction of increased circularity in water management will gain importance in Germany due to declining water availability coupled with growing pressure on water resources. The main reason for this is rising temperatures as a result of climate change, which lead to increased evaporation and higher water consumption, particularly for irrigation purposes. Additionally, some regions are experiencing rising population numbers, as exemplified by the Berlin area. Alongside rainwater management measures (blue-green infrastructure, sponge city principles) and the reuse of treated wastewater, Managed Aquifer Recharge (MAR) represents another fundamentally suitable method for returning water to the cycle. Compared to technical storage systems, a key advantage lies in the activation of naturally existing storage spaces, which offers significant economic as well as planning-related benefits. Against this background, the present work investigates, using the example of the Günz River, whether the quality of runoff is suitable for MAR and how the quality can be effectively monitored.

The study addresses a highly topical issue that is of great relevance in many regions of Germany and certainly also in other countries. Moreover, it is very practice-oriented and even provides a concrete proposal for setting up monitoring stations. The results are presented clearly and are easy to follow.

We would like to thank the reviewer for this valuable, supportive feedback and for highlighting the importance of the discussed topic. We hope that the adjustments are in the reviewer's interest and will further improve our manuscript.

Suggestions for improvements:

- The manuscript should discuss in more detail the transferability of the results to other river catchments. We agree that the manuscript benefits from a clearer discussion of the transferability. Here, we have to distinguish between the transferability of the methodology and the transfer of the site-specific results. The methodology itself is site-independent and transferable to regions with different hydrological and hydrogeological conditions. Nevertheless, we consider the rural-urban distinction and the size of the watershed to be the primary factors influencing the applicability. We clarified this key limitation more explicitly in the discussion (line 524-531). While the study site stands representative of many rural catchments, the actual results are likely site-specific. However, they show the potential of MAR with river water in rural catchments with similar characteristics, as well as the potential of linking watershed risks with quality measurements.

- The manuscript should also address the aforementioned alternative or complementary methods. MAR does not necessarily have to be implemented centrally at major rivers but can also be realized in a decentralized manner within the catchment area.

Regarding the implementation of MAR, we fully agree with the reviewer that especially the upper catchments are promising locations. Although MAR is a versatile tool that can be implemented even at longer distances to the river, infiltration near major rivers often faces constraints due to high volumetric flows and elevated groundwater levels. Additionally, coupling MAR with direct flood protection measures is typically not feasible at major rivers. We further clarified in the introduction that we understand the presented potential MAR scheme as decentralized MAR (line 95-102).

Referee #3

The scope of the paper is very unclear and so the reasoning behind the paper and your arguments. Is the focus on MAR and how river water quality and quantity affect its performance or is it on rivers and how MAR affects their quality and quantity. Or is it on something else: eg. Testing monitoring setup? Please clarify and adjust the text accordingly. Particularly, the introduction is confusing, please state clearly your hypotheses and objectives.

We thank the reviewer for this critical comment. The aim of this paper is to present a methodology for assessing river water quality with regard to its potential use as a source for MAR. Since laboratory confirmation of water quality typically occurs on a different time scale than flooding events, the quality of the source water must be ensured intrinsically. We propose that this can be achieved through a combination of high-resolution monitoring at strategically selected sites, a limited number of targeted laboratory analyses, and a risk assessment of the catchment. The new methodology was applied exemplarily to a river in southern Germany, which is representative of many rural watersheds of similar size. The methodology itself is site independent and transferable to regions with different hydrological and hydrogeological conditions. In the revised manuscript, we communicated the primary focus and structure of the study more clearly. We restructured the paragraph starting in line 95 and clarified the presentation of our hypotheses and aims by adding two sentences (line 95-102).

The section on Examples of safeguarding water quality can be derived from the drinking water sector should be shortened or even removed from the introduction as far too long.

The section on examples of safeguarding water quality was indeed detailed, which we tried to tweak by deleting the three sentences on the implementation of the Water Safety Plan concept in Germany (line 48-52).

Discussion should be structured with meaningful headings and address set up in the introduction hypotheses and objectives. At the moment it is rather dense, difficult to follow and spoiled with unnecessary details. Please streamline it.

We structured the discussion with subheadings and are now picking up the main research questions and hypotheses from the introduction (line 419, 426, 491, 503, 523).

line 5 grammar

We rechecked our abstract with a grammar checker, but found no incorrectness in line 5.

We hope these changes improve the clarity and focus of the manuscript and appreciate further consideration.

All manuscript revisions

Line 9-10 Grammatical correction.

Line 11 Grammatical correction.

Line 13 Grammatical correction.

Line 16 MAR abbreviation was used without introduction as noted by Referee #1.

Line 26 We removed spaces before % as suggested by Referee #1.

Line 47 Grammatical correction.

Line 48-52 We shortened this section in the introduction as suggested by Referee #3.

Line 54 Referencing adjusted.

Line 63 Referencing adjusted.

Line 95-102 We communicated the primary focus and structure of the study more clearly, as inquired by Referee #3.

Line 120-122 We removed spaces before % as suggested by Referee #1.

Line 123-124 We added the climate classification of the area to simplify transferability.

Line 127-128 We removed spaces before % as suggested by Referee #1, and removed one unit error.

Line 142 Referencing adjusted.

Line 146-147 Abbreviation already introduced.

Line 171 Tense adjusted.

Line 181 Referencing adjusted.

Line 226-227 Referencing adjusted.

Line 228 Referencing adjusted.

Line 236 Referencing adjusted.

Line 245 We removed spaces before % as suggested by Referee #1.

Line 248 Referencing adjusted.

Line 254 Referencing adjusted.

Line 260 We removed spaces before % as suggested by Referee #1 and corrected a grammatical error.

Line 261 Abbreviation already introduced.

Line 264 Referencing adjusted.

Line 273 Referencing adjusted.

Line 276 Abbreviation already introduced.

Line 281 Referencing adjusted.

Line 300 Tense adjusted.

Line 303 Referencing adjusted.

Line 309-310 Abbreviation already introduced.

Line 314 Tense adjusted.

Line 352 We removed spaces before % as suggested by Referee #1.

Line 359 We removed spaces before % as suggested by Referee #1.

Line 385 Referencing adjusted.

Line 409 Tense adjusted.

Line 419 We structured the discussion with subheadings as suggested by Referee #3.

Line 426 We structured the discussion with subheadings as suggested by Referee #3.

Line 445 Referencing adjusted.

Line 461 Referencing adjusted.

Line 479 Abbreviation already introduced.

Line 487-488 Referencing adjusted.

Line 491 We structured the discussion with subheadings as suggested by Referee #3.

Line 503 We structured the discussion with subheadings as suggested by Referee #3.

Line 505 Referencing adjusted.

Line 515-522 In the course of restructuring the discussion, we moved this paragraph down to line 538-544.

Line 523 We structured the discussion with subheadings as suggested by Referee #3.

Line 524-531 We discussed in particular the transferability of the methodology as proposed by Referee #1 and #2.

Line 538-544 As part of the restructuring of the discussion, we have moved the paragraph that was originally in lines 515-522 to this location.

Line 546 We adapted the wording as suggested by Referee #1.

Line 554 Tense adjusted.

Line 566-568 We have added a sentence in the conclusion pointing to the potential next steps as suggested by Referee #1.