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Biogeosciences Editorial Team

20. Oktober 2022

Dear Dr. Bond-Lamberty,

hereby I submit a revised version of our manuscript *"Ideas and perspectives: Land-ocean connectivity through groundwater"* to be considered for publication in Biogeosciences.

We are glad to see that our manuscript has been well received and are now invited to upload the newest version. Attached we are sending the marked-up document which includes the changes highlighted in our replies to the community (CC) and reviewers' (RC1, RC2) comments. In addition to those changes, we corrected a few typos which we identified during the review and included two new (2022) relevant references. A detailed list of those changes is provided below (see Annex 1).

We appreciate your attention and look forward to your reply.

Yours faithfully,

Damian L. Arévalo-Martínez

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Annex 1 – Additional changes to the manuscript

These changes were not derived from the community and reviewer's comments, but from the authors' own assessment of the revised version after implementing the replies to those comments.

- l. 4–28 Numbering of affiliations updated to accommodate the new affiliation of the first author
- l. 150 Replaced "from which" by "of which"
- l. 183–184 Ordered citations chronologically
- l. 189–190 Added reference from new study on methane release from pockmarks in association with FSGD (Purkamo et al., 2022)
- l. 221 Replaced "sustained monitoring the" by "sustained monitoring of the"
- l. 258 Changed "coast line" by "coastline"
- l. 319 Changed "model" to "models"
- l. 326 Deleted second occurrence of "offshore"
- l. 334 Deleted "can"
- l. 394 Replaced "identification" by "detection"
- l. 399 Added reference from new study on biogeochemical aspects of FSGD (Ikonen et al., 2022)
- l. 408 Removed capitalization from "Radon" and "Radium"
- Acknowledgements: test modified such that the main grant for the paper is listed first (FON2020-03)
- l. 484–485 Additional acknowledgement to reflect contribution of DFG research group "DynaDeep"
- l. 487 Changed "is" by "was" since DLAM changed institution during the review process of the manuscript
- Reference list

Adjusted position of Liu et al. (2010) and (2017) to keep chronological order

Added: Ikonen, J., Hendriksson, N., Luoma, S., Lahaye, Y., and Virtasalo, J. J.: Behavior of Li, S and Sr isotopes in the subterranean estuary and seafloor pockmarks of the Hanko submarine groundwater discharge site in Finland, northern Baltic Sea, Appl. Geochem., 105471, https://doi.org/10.1016/j.apgeochem.2022. 105471, 2022.

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Added: Purkamo,L., Milene, C., von Ahn, E., Jilbert, T., Muniruzzaman, M., Bange, H. W., Jenner, A.-K., Böttcher, M. E., and Virtasalo, J. J.: Impact of submarine groundwater discharge on biogeochemistry and microbial communities in pockmarks, Geochem. Cosmochem. Acta, 334, 14–44, 2022.

Author's response to community comments (Dr. Clara Ruiz-González)

Very relevant and timely article! The authors might consider including a recent review on the microbial dimension of submarine groundwater discharge by Ruiz-González, Rodellas and Garcia-Orellana (2021, FEMS Microbiology Reviews), which evidences the poor knowledge of the (micro)biological aspects related to submarine groundwater discharge, ranging from the microbially-driven chemical transformations of the groudnwater within coastal aquifers to the microbial responses to groundwater inputs once in the coastal ocean. Current challenges and future directions of the field are also highlighted, empashizing, as in the current article, the need for multidisciplinary collaborations. This review article was published slightly earlier than the one of Archana et al (2021), already cited in the text, but targets the entire groundwater-marine continuum by discussing the microbial implications of groundwater discharge in the ocean.

Clara Ruiz-González, Valentí Rodellas, Jordi Garcia-Orellana, The microbial dimension of submarine groundwater discharge: current challenges and future directions, FEMS Microbiology Reviews, Volume 45, Issue 5, September 2021, fuab010, https://doi.org/10.1093/femsre/fuab010

Many thanks for your interest in our manuscript and the suggestion. The (micro)biological aspects of both freshened submarine water discharge and offshore freshened groundwater certainly need further investigation, and their role within future multidisciplinary approaches is of course a topic we would like to highlight with our contribution.

We have included now the suggested publication in the revised version of the manuscript (l. 251–252).

Author's response to reviewers' comments (bg-2022-148-RC1)

On behalf of the authors, I thank Reviewer #1 (Dr. Ana Silva) for the positive assessment of our manuscript, as well as the constructive comments and suggestions. On the following we provide a point-by-point response to the issues raised during the review process, and list/discuss the changes done to the revised version:

Overall this manuscript provides a short summarising view of groundwater as a linking element between land and sea. Its scope is adequate for the publication format and the argumentation is well made in several key points. The topic and scope are very timely and match a research area reaching a cumulative point of becoming useful in management contexts. Albeit of considerable utility to the target readers, the manuscript reads mostly as a summarising text, where the authors' own contributions appear very scattered and hard to find; summarising their original contributions at the end of the sections might be a simple solution to enhance the manuscript's uptake and impact. I made several annotations in the attached pdf to be considered by the authors. Most reflect a need to alter the document to become more reader-friendly and add some contribution ambition, which is somewhat limited in this version. The point made about the common language/proposed framework for existing methodologies would be a particularly desirable adding value.

Reply by authors:

Many thanks! We are glad to see that our manuscript is seen as useful for researchers from a wide range of expertise. We would like to clarify that with this manuscript we aim to present the readers our view with respect to the impelling need of developing a framework for joint, multidisciplinary studies on FSGD and OFG, rather than offering the framework itself or recommending an optimal combination of methods which should be used. We contend that identifying the current data and process understanding gaps in FSGD/OFG research (as presented in this manuscript) is precisely the author's contribution requested by Reviewer #1.

l. 74–76 This may be a limited definition as it seems to leave out the groundwater flowing at the surface from coastal aquifers into the intertidal zone. I encourage the authors to add information and arguments positioning this situation in their 2-element classification. for instance see:
https://www.sciencedirect.com/science/article/abs/pii/S0141113622001179

Reply by authors:

Thank you for the suggestion. We disagree in that our definition disregards FSGD into the intertidal zone, since it generally refers to flows of groundwater to the ocean, independent on the level at which this might occur. However, we would like to avoid other readers having the same impression and therefore changed slightly our formulation so that it is clear that we refer to fluxes into the ocean through the coastal zone (which by definition includes the intertidal). We hope this clarifies the confusion. The revised sentence reads as follows: *"The first comprises meteoric groundwater flux from terrestrial aquifers through the seabed (including the intertidal zone) into the coastal ocean, (...)"* (l. 75–76 of revised manuscript).

l. 103–108 given this self-proposed context I suggest for sections 1+2 have a dedicated subheading focusing on current bottlenecks/limitations/gaps so that the reader can obtain a summary of where we are now in this research,ie, state of the art. This would also help further in justifying the review pertinence.

also and importantly, given that the authors claim here existing issues related to subfield-languages heterogeneity, I would expect this review to be greatly imprived by adding the objective of creating a standardised framework integrating the most promising methodologies and proposing a common language. this would enable a practical uptake of this manuscript, enhancing its impact.

Reply by authors:

Thank you for the suggestions. We would like to clarify that our manuscript purposefully deviates from a review paper, since we think there is already an important number of excellent papers of that type which address the specifics of our current knowledge on e.g. hydrological, geological, geochemical and biological aspects of groundwater fluxes and reservoirs.

We contend that we have included information on bottlenecks/limitations/gaps throughout the different sections of the paper. Considering that these aspects can look different depending on whether we are discussing, for instance, spatial distribution or environmental impact, adding subheadings to sections 1 and 2 (as suggested by Reviewer #1) would imply adding them uniformly through all sections. Including subcategories that apply to all sections is rather unfeasible and we think the result would not be in the best interest of the reader because of an unnecessary increase in the complexity of the document.

Moreover, the main goal of our manuscript is not to provide a unique framework which can be used by all groups conducting research on FSGD and OFG, but rather to convey the need of developing it and provide examples on its added value, should it be used for future multidisciplinary studies. In summary, we hope that our contribution fosters future (international) initiatives for joint investigation of FSGD and OFG.

l. Section 3 This section requires additional sublevels of subheadings categorization given its extension and scope; as it is, the reading flow becomes very cumbersome

Reply by authors:

Thank you for the suggestion. However, we respectfully disagree. This section comprises five interrelated paragraphs which follow a logical sequence that would be interrupted by sublevels. Also in this case we do not think that separating the text would help the reader to grasp the arguments presented in this section.

l. 175–177 This requires further explanation/detail to support the argument pertinence

Reply by authors:

Thank you for the suggestion. We changed our formulation in order to strengthen our argument. The revised sentence reads as follows: *"In contrast, the role of OFG as a fresh- or brackish water habitat within a purely marine environment remains unknown and might constitute a new frontier in ocean sciences, also in view of its potential exploitation as an unconventional source of water."* (l. 176–178 of revised manuscript).

l. 360–362 consider adding here also this alternative method based on thermal imagery: https://www.mdpi.com/2077-1312/10/3/414

Reply by authors:

Thanks for the suggested reference. We have added it, both within the text (l. 365–366 of revised manuscript) and the list of references.

Section 5 I strongly encourage the authors to provide here either a method-focused summarised figure or table. This section is very long, detailed and for the readers benefit, the authors should finish with their proposed (combination of methods?) solution for different scenarios

Reply by authors:

Thank you for the suggestion. As explained above, the purpose of our manuscript is not to provide an "ultimate" guideline on how to carry out joint FSGD/OFG research, but rather to identify the current gaps as well as potential ways of cooperation to address those gaps. We are reluctant to provide a "recommended" approach, since to that end a higher level of international coordination would be needed. The realization that activities to achieve that coordination is timely, is precisely what we would like to bring to the community with this manuscript. As for the length, we respectfully disagree since we see no reason why this particular section should be further shortened (it is indeed the shortest of the manuscript).

l. 466 I strongly encourage the authors to add a "conclusion" section focusing in the impacts of their analyses and discussions in the manuscript, ie, added value of the proposed tasks as a whole, contours/preliminary framework for unifying/merging methodologies and common language approach,

Reply by authors:

We respectfully disagree. In our opinion, a conclusions section is not appropriate for this type of manuscript because we are not presenting and/or discussing scientific results. Moreover, considering the length of the paper, a summary of the arguments brought about within it would not represent a significant contribution. With our last section (5), we instead hope to convey suggested ways forward which are derived from the knowledge gaps which were discussed in the previous sections.

l. 1020 For the readers' support I suggest this table to include some example references. I also leave for your consideration this reference: https://www.sciencedirect.com/science/article/abs/pii/S0141113622001179

Reply by authors:

Thank you for the suggestion. We added the study to the text (l. 184 of revised version) and list of references since it fits well within the context of the manuscript. As for Table 2, example references of the different approaches have been included/discussed in the manuscript. We therefore do not see necessary to include them there. Considering that there are several references that can be used for each method, we opted for avoiding the bias that would imply selecting certain studies and "recommend" them as promising.

Kind regards,

Damian L. Arévalo-Martínez

Author's response to reviewers' comments (bg-2022-148-RC2)

On behalf of the authors, I thank Reviewer #2 for the positive assessment of our manuscript, as well as the constructive comments and suggestions. On the following we provide a point-by-point response to the issues raised during the review process, and list/discuss the changes done to the revised version:

This article provides a summary of the important roles, ideas, and prospects of groundwater as an important link between land and sea. In particular, the authors classify meteoric groundwater into coastal runoff FSGD and offshore freshened OFG, and emphasize the role of each and the connectivity between the two. This manuscript is very timely and necessary as the definitions scattered in several papers were arranged, the latest research from around the world were cited, as well as a perspective or direction for groundwater study is provided. Nevertheless, some suggestions are annotated in the attached pdf to help the reader understand.

Reply by authors:

Many thanks, we are glad to see that the relevance of our contribution comes across clearly and that the manuscript is seen as useful for researchers from a wide range of expertise.

l. 147 ($1*10^6$ km^3) Readers may not know what this number means and whether it is important or not. It would be better if a suitable metaphorical example could be provided to give the reader an idea of this quantity.

Reply by authors:

Thanks for the suggestion. To offer the reader a point of comparison for this number, we added the percentage it would represent in with respect to the estimated total fresh water sources on Earth. The revised sentence reads: *"Recent estimates report OFG to comprise a volume of approximately 1*106 km3 (Micallef et al., 2021), which is about 10% of the Earth's liquid fresh water (Shlklomanov, 1993)."* (l. 146–148 of revised manuscript). We added the corresponding entry to the list of references.

l. 218 also in Jeju Island, Korea (Kwon et al., 2017 Scientific reports; Cho et al., 2019 Science of the total environment)

Reply by authors:

Thanks for the suggestion. We adjusted the sentence to accommodate the additional case studies. The revised sentence reads: "*For example, large outbreaks of the macroalgae Ulva spp. (so-called "green tides"), which occur regularly in eutrophic coasts off China and Korea, are attributed to the nutrient supply by FSGD (Kwon et al., 2017; Liu et al., 2017; Cho et al., 2019; Zhao et al., 2021).*" (l. 218–220 of revised manuscript). We added the corresponding entries to the list of references.

l. 241–249 For readers support I suggest this part to include some references.

Reply by authors:

Thanks for the suggestion. We added three references of papers which present comprehensive overviews on the methodologies used for geophysical, hydrological, biogeochemical and microbial approaches to investigate FSGD/OFG (l. 251–252 of revised manuscript). We added an entry to the list of references, since one of the publications was not originally cited in our manuscript:

Clara Ruiz-González, Valentí Rodellas, Jordi Garcia-Orellana, The microbial dimension of submarine groundwater discharge: current challenges and future directions, FEMS Microbiology Reviews, Volume 45, Issue 5, September 2021, fuab010, https://doi.org/10.1093/femsre/fuab010

We are thankful to Dr. Ruiz-González, who made us aware of the paper as part of her community comment to our manuscript.

l. 995 How about displaying it as "FSGD site" rather than FSGD for uniformity?

Reply by authors:

Thanks for the suggestion. However, in our manuscript we are trying to convey the point that when we refer to FSGD we are talking about fluxes, whereas when we refer to OFG we talk about reservoirs. Adding a reference to "FSGD sites" in this context might lead to confusion. Moreover, the spatial distribution of FSGD occurrences can be seen in Figure 2.

l. 995 How about additionally displaying the distance scales corresponding to the FSGD site and OFG site?

Reply by authors:

Thanks for the suggestion. However, we don't see an added value in including the scale distances in this context, since our manuscript is focused on the conceptual aspects of both fields of research, rather than the details of the methodological needs that might arise due to different scales of variability. Thus, adding the scales might unnecessarily complicate the figure for the reader. The different scales of variability are included in some of the review papers which we cited in our manuscript (e.g., Bratton, 2010).

Kind regards,

Damian L. Arévalo-Martínez