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Hydrology and Earth System Sciences
Discussions

Interactive comment on "Combining resistivity and frequency domain electromagnetic methods to investigate submarine groundwater discharge (SGD) in the littoral zone" *by* Marieke Paepen et al.

Anonymous Referee #1

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This manuscript presents an interesting set of methods and data to generate a complete overview of a study area on the coast of Belgium. The use of geophysical methods is very extended in the study of groundwater in coastal setting and combined methods optimizing their use can be applied in other regions. There are several relevant facts presented and discussed that can be valuable for the scientific community but the text needs improvement in multiple sections to provide a more specific message and to align better the content of the manuscript.

Specific comments

Abstract

The abstract can be improved. General descriptions as lines 10-14 or very specific details about geophysical methods can be replaced by a more clear overview of the research conducted and the new insights provided by this manuscript.

Introduction

The concept of SGD has to be polished. Along with the text, it can be inferred that authors refer in most of the cases to fresh or terrestrial SGD even if in the introduction there is a brief mention about recirculated/saline SGD. I think the authors should update this way of referring to SGD. To get an update about this topic they can start by the beginning:

Moore, W.S., Church, T.M., 1996. Submarine groundwater discharge. Reply to Younger (1996). Nature 382, 122.

And keep track of the recent advances especially about the saline part of SGD that is what it is usually a more unknown element for the hydrology community:

Rodellas, V., Stieglitz, T. C., Andrisoa, A., Cook, P. G., Raimbault, P., Tamborski, J. J., Radakovitch, O. (2018). Groundwater-driven nutrient inputs to coastal lagoons: The relevance of lagoon water recirculation as a conveyor of dissolved nutrients. Science of the Total Environment, 642, 764-780

Or by recent reviews/discussions:

Taniguchi, M., Dulai, H., Burnett, K. M., Santos, I. R., Sugimoto, R., Stieglitz, T., Burnett, W. C. (2019). Submarine groundwater discharge: Updates on its measurement techniques, geophysical drivers, magnitudes, and effects. Frontiers in Environmental Science 7.

Duque, C., Michael, H.A., Wilson, A.M. (2020). The subterranean estuary: Technical term, simple analogy, or source of confusion? Water Resources Research 56.

The introduction would benefit from being more specific, in its current state it is too

broad without a clear thread about what wants to be showed. The review of multiple cases studying SGD is not really showing what are the gaps in the current use of methods or research questions that need to be addressed. For example lines 15-17, page 3 are out of context and could be deleted as well as page 2, lines 31-33.

On the contrary, page 3, lines 26-31 is a good example of how should be done the introduction, adding references to these sentences would be a better way to probe the utility of this study showing cases about SGD with spatial and temporal variability/ the challenge of work in coastal settings /studies discussing the problem of the gap between land and sea. I suggest a full reorganization of this section rewriting part of it.

Some additional references that can be useful:

Stieglitz, T., Rapaglia, J., Bokuniewicz, H. (2008). Estimation of submarine groundwater discharge from bulk ground electrical conductivity measurements. J. Geophys. Res. Ocean. 113, 1–15.

Stieglitz, T., Taniguchi, M., Neylon, S. (2008). Spatial variability of submarine groundwater discharge, Ubatuba, Brazil. Estuar. Coast. Shelf Sci. 76, 493–500.

Kinnear, J.A., Binley, A., Duque, C., Engesgaard, P.K. (2013). Using geophysics to map areas of potential groundwater discharge into Ringkøbing Fjord, Denmark. Lead. Edge 32.

Study area

The geology elements used in the discussion must be initially presented in the study area section. For example, it is mentioned a clay layer very important for the interpretation of the data but it is not explained previously. Also, this layer can be probably inserted in the geophysical interpretation in the figures as lithological columns (or any other graphical way) to probe the reliability of the method.

What is the local water problem that wants to be solved in the study area? It is mentioned in the text but not clearly. Is any interest in increasing the pumping rate? In the

text, it is said that the pumping rate has been decreased in the last years.

Methodology

In general, it should be mentioned how many measurements/cross-sections have been collected for each method.

Page 5, line 20. Is this needed to be explained for any reason? If the collection is easier and faster there is no reason to use the other method.

Page 5, lines 24-25. Is this an innovation of this study compared with others?

Page 6 lines 10-12. I think the data generated by broken electrodes must be removed both from the text and the figures, they do not provide any value.

Results and discussion

One of the main issues in the text is the disorganization in the section results and discussion. This makes it difficult to read and the final message is not well transmitted. I strongly encourage a complete reorganization of the results and discussion, for example by dividing the text into the following sections with a heading:

- CRP data (clear specific presentation of the data without mixing with other sections)

- FDEM data (clear specific presentation of the data without mixing with other sections)

- ERT data (clear specific presentation of the data without mixing with other sections)

- Advantages of the combined methodology (compared with previous studies)

- Geophysical innovations (technical improvements, novelties, and new approaches)

- Seasonal SGD changes and over the last 20 years (showing the data from previous reports)

I think that the approach to present the data as “they were collected in the field” is not working well enough to be justified.

Along with the text, there are multiple mentions to a “freshwater tongue” below the salty water. This is a well-established field of research that the authors should check to put into context their findings.

For example:

Robinson, C., Gibbes, B., Li, L. (2006). Driving mechanisms for groundwater flow and salt transport in a subterranean estuary. Geophys. Res. Lett. 33, 3–6. . . .And all the following papers based on modeling and field observations. There are dozens but this is one of the first ones.

Avoid referring to figures as right/left side, better say any cardinal direction or even mark in the figure the parts that want to be highlighted.

Page 9, line 1. How do you know the origin of the brackish water?

Page 9, lines 8-12. The discussion about the comparison with previous surveys is totally out of context, as said before, better create a full section of comparison where the old data are also presented maybe even graphically. This applies also for the following comparisons in other pages.

Page 10, lines 10-13. This paragraph seems to be out of context. Better move a section about geophysical innovations/progress as said before. The same for other paragraphs where geophysical technical aspects are commented.

Page 10, line 22. What is the dike between the beach and the dunes? This should be presented in the study area section.

Page 10, line 22. The effect of local heterogeneities is ambiguous, specify better or remove.

Page 11. Line 2, is an example of the wrong use of recirculated water. The authors can refer simply to mixing between fresh and salty, or maybe to variable density-driven flow, but recirculated here is not meaning what the authors want. In general. they should

check this along with all the text after reading the general references provided before.

Page 11, lines 10-20. These methods of testing the results should more clearly be specified in the methods section.

Conclusions

Following the structure proposed for results and discussion, the conclusions can be more structured highlighting the novelties and new insights of this study. Page 12, line 15-16. Not needed, delete.

Figures

The figures are especially relevant in this manuscript as they contain all the data presented, it is, therefore, essential that they are as clear as possible.

The figure captions can be improved, technical data as error and dates can be removed (these data can be added in a table for example or commented in the text). A legend including all the lines in the figures (dotted black, dotted white, continuous. . .) would help in the interpretation, it is quite difficult for the reader to do it in its current state.

Another important improvement would be to differentiate the water column over the aquifer. As this is a research about groundwater, the properties of the sea are not that needed in the figures and would help in the graphical interpretation of the results.

If there are specific areas of the cross-sections the authors want to refer to during the explanations, they can mark them in the figures to facilitate the link between text and figures.

I understand that the location of the cross-section in the figures corresponds with the spatial location, even if this is not clearly stated. The authors can add a reference point so the reader can know always how far is from the shoreline (i.e, distance to the high/low tide mark/dunes/).

Also, all the profiles must have the same markers, for example, the dash lines in figure

4 are only in two of the cross-sections. In general, any improvement to give a better overview of the location of the cross-section would benefit the figures.

It is not clear reading the figure caption of figure 7 what are the differences between A, B, C and D. Figure 8 is difficult to follow even after reading the text (maybe because it is quite brief). A presentation of the results adapted to the purpose might be considered instead of presenting the data in the same format as in the analysis of the results (for example showing the difference in resistivity between inversion models).

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