

26 Jun 2024; Uploaded files validated; by Natascha Töpfer; Notification to the authors:

Checking your paper, I noticed that your tables contain coloured cells. Please note that this will not be possible in the final revised version of the paper due to HTML conversion of the paper. When revising the final version, you can use footnotes or italic/bold font. For now, the process will continue, but please note that the final version cannot be published by using coloured tables.

[REPLY: We have adopted the tables accordingly \(colors are removed from the tables\).](#)

Revision, 08 Sep 2024

Editor decision: Publish subject to minor revisions (review by editor)

by Yongping Wei

Public justification (visible to the public if the article is accepted and published):

The manuscript has been improved a lot. Please address the very constructive comments from Reviewer 2, particularly the structure of your introduction section and other detailed comments. In addition, you should address technical corrections.

[REPLY: Thank you very much, we have answered to all comments in the following and implemented most of them in the manuscript.](#)

Report #1, Submitted on 09 Jul 2024, Anonymous referee #3

For final publication, the manuscript should be:

accepted as is.

Suggestions for revision or reasons for rejection:

I have no concerns about the current version of the manuscript, and recommend be accepted by the HESS journal. It is time to go forward and publish it.

[REPLY: We thank the reviewer for the comments and time in reviewing our manuscript.](#)

Report #2, Submitted on 14 Aug 2024, Anonymous referee #4

For final publication, the manuscript should be:

reconsidered after major revisions.

Suggestions for revision or reasons for rejection:

General comments:

The paper presents an analysis of measures aimed at restoring groundwater ecosystem services in the Grand Bahamas. A technical assessment of the potential for Managed Aquifer Recharge (MAR) is combined with a cost-benefit analysis (CBA) that applies two different system boundaries (referred to as a financial and an extended CBA). The underlying problem

and the aim of combining a technical assessment and CBA to enable a more holistic analysis to identify sustainable mitigation measures are relevant and fit the journal's scope. An interesting case study is presented, and relevant aspects related to the applied methods and environmental challenges relevant to Grand Bahamas and similar areas are presented. The current structure (e.g., the problem description and aim in relation to how the results are presented) makes it unclear what the manuscript's primary aim and novelty are. For example, according to the title the focus is on groundwater ecosystem service restoration, but since one of the analysed measures is reforestation, which has no (or rather no analysed) effects on the groundwater ecosystem services, it is a bit confusing for the reader. It is of course possible to compare measures with different purposes, but since much of the manuscript focuses on MAR and the drinking water supply, it becomes unclear. Furthermore, it should be more clearly demonstrated how the proposed method enables the extended CBA, i.e. how it overcomes the perceived weaknesses of CBA.

Below, more detailed comments are provided related to the above mentioned aspects and some other details.

REPLY: We thank the reviewer for the constructive feedback and detailed review, we answered the specific comments below. ***Line numbers refer to the revised manuscript, in its version of the tracked changes mode***.

Specific comments:

Abstract: I miss a comment on the generic results and novelty of the paper, i.e. not only the case study results but also the conclusions and contributions related to the methods or similar.

REPLY: We have extended the abstract, accordingly.

Lines 21-25: MAR only provides 10% of the water demand, but reforestation provides 0% even though the extended CBA show that it is profitable. So, it is important to remember what decision criteria are used. Is it to find the most profitable measure that mitigate any of the damage caused by the hurricane or is it specifically to improve the drinking water supply/restore groundwater ecosystem services?

REPLY: we have changed the wording of Line 22 for being more clear (referring the 10% the the MAR scheme mentioned in the sentence before). Additionally, we would like to remind the reviewer that the MAR scheme's main purpose is to respond to the restoration of groundwater ecosystem services, hence the focus on that aspect, while the reforestation measure has the aim of restoring the forest ecosystem. Both measures lead to additional effects.

Line 36: forest, is it not more appropriate to use the term terrestrial ecosystems?

REPLY: we agree and have adjusted the wording for being more general, now reading "Both island inhabitants and terrestrial ecosystems (including forests)..." (line 38).

Line 65: The RO's high energy consumption is highlighted here. Should the social cost of carbon emissions due to energy consumption be included in the CBA, or is the energy production not causing any CO₂ emissions?

REPLY: we agree that energy consumption could be a source of CO₂ emissions, which could potentially also be included in the CBA. However, including potential CO₂ emissions could

be done for other measures as well, and this goes beyond our capacity and the scope of the study. We will consider adding this aspect in extended CBAs in future work.

Line 64-66: You refer to potential future hurricanes and the potential consequences to the existing RO system and other infrastructure. This is used as a motive for additional measures, but to fully consider this a probabilistic and risk-based approach could have been needed where the probability of future hurricanes and the consequences of them could have been included in the CBA (i.e., the consequences differ between the different alternatives depending on if GB is fully dependent on RO or not). I understand this has not been done and cannot be added now, so this is just a comment on how such aspects typically are included in risk-based CBA.

REPLY: Thanks for the comment, we agree that there is a high probability of hurricanes also in the future. As you correctly state, we did not consider a reoccurrence of the hurricane which could lead to, e.g., the destruction of the reforested area, or further salinization of the freshwater lenses. For once because we would not know how destructive the next hurricane would be and second because we wanted to show the costs and benefits of restoring the ecosystem after Hurricane Dorian. With the current results we see that already restoring the ecosystem services are financially not profitable from Hurricane Dorian, and thus we suspect even a more negative assessment for the forest ecosystem. Regarding the groundwater ecosystem, we suggested mitigation and contingency actions, to be designed to withstand another hurricane event, e.g. We agree that a probabilistic considering is highly relevant and interesting. However, we feel that this goes beyond our study; we recommended this task for future work.

Lines 72-74: You state that “NBS are considered cost-effective and viable solutions”. Is it not more appropriate to say that they typically are since all types of NBS are not always cost-effective?

REPLY: We agree, we have changed the wording, accordingly.

Lines 75-76 (this also relates to several other parts of the manuscript): It is stated that two NBS measures to mitigate the impacts of Dorina on groundwater ecosystems are analysed. Since a technical feasibility assessment is performed and the focus is on drinking water supply, it is natural to think that the measures aim to improve access to drinking water. However, reforestation has no effect on water supply, so as a reader, I wonder if the aim is to evaluate any measure that may mitigate the impacts of Dorina. Earlier in the manuscript (line 51), you mentioned that measures to mitigate both groundwater and forest ecosystems were implemented. According to the title, the focus is on groundwater. I suggest you clarify the focus of the paper and why the analysed measures are included.

REPLY: We agree with the reviewer, that reforestation measures have not been studied in terms of their effect on the freshwater lenses, as stated in line 495-498. Further we agree that we should make a differentiation between the aim of the MAR scheme and the forestation measure. We have rephrased line 77-78, accordingly. In line 516-522 we have already stated that we differentiate between the aim of the two measures. We have considered your input also by rephrasing the paper title.

Lines 81-91: You state that CBA “falls short of adequately monetarize ES”. There are numerous examples of how CBA has been applied to consider effects on ES and is it not rather so that the problem is not the method as such but how it is applied and that there may

be a lack of valuation data to properly value economically the ES? You correctly state that all benefits and costs should be included in a CBA. This is, of course, typically not possible, and limitations are done. However, all relevant benefits and costs should be identified, but some may be excluded from the analysis due to different reasons. Based on this, I have two comments: (1) you state that you propose a method combining a technical feasibility assessment with CBA to (as I understand it) overcome the problem of overlooking ES. However, based on the presented results, it is not clear how the feasibility assessment improves the identification of relevant ES; (2) You do not present a thorough identification ES and related costs and benefits. The analysed ES are presented (lines 221-224), but how was this done, did you use CICES or any other classification system to ensure no ES were overlooked?

REPLY: In line 83-86 we refer to the CBA as it has been conducted often in the past, also based on guidelines and recommendations of what aspects should be included in a CBA. We change wording in line 84 to “the CBA method, and the way it has been recommended to be conducted in the past, falls short to adequately monetarize ecosystems services”.

Lines 120-123: Wellfield 6 constitutes approximately 42% of the total abstraction rate (26/11), but you state that it corresponds to 30% of the total demand. Does it have a higher capacity compared to the actual demand? Please clarify this. In the abstract, it is stated that Dorian caused 40% of the island’s water supply to become brackish.

REPLY: In the abstract we had rounded the number of water abstraction from wellfield 6 to 40% (we have now added “about”, before this percentage). As stated in line 120-121, 11356 m³/day are abstracted from wellfield 6, out of a total average subtraction of 26497 m³/day on GB. This corresponds to 42.86% of total water abstraction from wellfield 6. These 42.86% (rounded up to 43%) of the total water abstraction are supplied to 30% of the water users, as described line 126. Meaning that 30% of the users consume that fraction (43%) of the total abstracted water. We made that clearer, now, by adding the percentage(s) to line 121 and 126.

Line 135: “sustainability measures (e.g., reforestation)”, but you only analyze reforestation and no other sustainability measures.

REPLY: We also consider the MAR measures to be sustainability measures and have reformulated this sentence, for being clearer (line 140-141).

Section 2.2. (Figure 2, etc.): The CBA in both part 2 and part 3 shows what is most profitable; the only difference is that different system boundaries have been applied. In the first case, the focus is on the water supply, so e.g. what is most profitable with respect to water supply. Part 3 identifies the measure most profitable from a societal point of view. This does not make part 3 a novel type of CBA, it is a common type of CBA sometimes referred to as social CBA. The manuscript would benefit from a comment on system boundaries, i.e. which parts of society are included in part 2 and how does it differ from part 3 (global perspective or not?). Linked to a previous comment (lines 81-91), I also suggest you elaborate on how/if the feasibility assessment facilitates the CBA in step 3 or not.

REPLY: We already used the phrase “social ... CBA” in line 225. We added a comment on system boundaries in line 94-96: “In other words, a standard CBA focusses on the analysis within the boundaries of the technosphere, i.e., the sphere of human-made technologies and systems, while the extended CBA encompasses studies of the measures’ effects on hydrosphere, atmosphere, and biosphere, in addition to the technosphere.” In our method, the

feasibility assessment is a pre-condition of the CBA. It can facilitate the CBA, as some information on the measures can be collected in advance for the feasibility study.

Section 2.4 and supplementary material (Table S1): Water price is used to value drinking water supply as an ecosystem service. Since there is typically no real market for drinking water, this will most likely not represent the true value of the drinking water supply. Due to lack of useful valuation studies (WTP etc.), this might be a reasonable assumption, but must be discussed since this is a key ES in the case study.

REPLY: We discussed limitations of evaluation methods in section 3.4.2, and especially in line 415-436.

Lines 193-194: You say all costs and benefits were identified, but this is with respect to the applied system boundaries.

REPLY: This was meant in a generic way. We understand this might lead to confusion, so we deleted “all” and added “within the system boundaries” (line 200).

Results section (but also the method): In a CBA, you typically present a reference scenario, and the measures are compared with this (i.e. what costs and benefits the measures cause). The current situation with RO implemented is presented in the manuscript, but RO is included as a measure. Therefore, the reference scenario/alternative is the current system without RO. The manuscript would benefit from a clear presentation of what is used as the reference scenario.

REPLY: Thank you for the comment. We added an explicit comment on the reference scenario in the methodology in line 220-221 and 268-269.

Lines 267: “the demand was calculated”, what calculations are done is it not only assumed equal to the abstraction rate for wellfield 6?

REPLY: True: the abstraction rate of Wellfield 6 is assumed to equal the water demand; we have rephrased this part.

Line 268: “30% of the current brackish water supplied” is it not 100% of the supplied brackish water but 30% of the total demand today?

REPLY: We have rephrased it to make it clearer.

Line 285-287: Is the conclusion based on the risk assessment that the final total risk is acceptable or how are the results used?

REPLY: In line 301-302 we wrote: “Based on the prior results... the following criteria for the selection of the most suitable MAR location were defined that also allow risk mitigation: “. With “prior results” we also address the results of the risk assessment; we designed risk mitigation measures in Section S3 (Supporting Information) and defined a residual risk after the mitigation measure. The identified and elaborated criteria that follow in line 302-306 are already including the mitigation measures to decrease the risks. We now have mentioned Section S3 directly there (line 301), for making this clearer.

Lines 314-315: An analysis of the distribution of costs and benefits in society is typically part of a CBA. Hence, this aspect can be considered in a CBA to make sure there is not an unreasonable distribution.

REPLY: We modified the text to: “Additionally, the question who would take over the costs for the RRWH schemes would need to be discussed as part of the CBA.” (line 328-329)

Line 325: has the option for recovering costs been considered in the analysis?

REPLY: No, this has not been included in the analysis.

Line 334: Here, the results are presented for a 4% discount rate, but in the supplementary material a discount rate interval from 1 to 10% is presented (and the results are also presented for this interval). 10% is an extremely high discount rate for a project like the one presented here. More recent recommendations from national authorities recommend a lower rate and in the document referred to (Floy, 2013), it is mentioned that discount rates ranging from 1 to 10% are reported in the literature, but the author recommends “2.2% for benefit-cost analysis with low and high values of 1.5% and 3.5% for sensitivity analysis”. If keeping the range 1-10%, please comment on what range is commonly applied.

REPLY: We consider 1 to 10% to display a higher range sensitivity analysis. We added the following explanation in line 362-363: “for a set of ten discount rates from 1% to 10%, as a sensitivity analysis, although the value of 10% goes beyond recommended discount rates values”

Lines 343-345: Since no benefits of reforestation are included, it seems to fall outside the scope of the analysis, and as a reader, you wonder why it is included.

REPLY: Water supply benefits are not included for reforestation, but reforestation brings other benefits (carbon sequestration, habitat quality, timber production) shown in the extended CBA. The mentioned sentence is used to highlight the difference between standard and extended CBA.

Lines 350-352: It is quite a strange comment since you earlier stated that it has no benefits, so it will of course not perform well in a CBA with the system boundaries applied.

REPLY: As replied above, this comment was used to highlight the difference between standard and extended CBA for reforestation.

Section 3.2 and 3.3: As earlier commented, MAR and reforestation have different purposes, and I suggest this is included when the results are discussed.

REPLY: We agree with your comment and tried made this more clear in the manuscript (see replies above). We feel that we are describing this in more detail in section 3.5 and 3.6, where we discuss the different purposes and aspects of MAR compared to RO and reforestation.

Line 409-: You only consider uncertainties in the discount rate, but the uncertainties in the model assumptions should be discussed. To what extent can the applied data for valuing the ES affect the results etc.?

REPLY: We extensively discuss limitations of the CBA methods later in section 3.4.2.

Lines 434-435: How do you ensure there is no double-counting?

REPLY: We could do that by using the MEA (2005) classification. We added this comment to line 448.

Lines 468-470: If this is included, the results may look different, so it is an important uncertainty to comment on when discussing model uncertainties.

REPLY: Thank you, we added the comment on potential additional uncertainties related to this aspect in line 483.

Line 506: You write two measures, but you include and analyse three measures since RO is considered a measure in the analysis.

REPLY: We feel that “the third one”, RO, is taken up two sentences later. We chose this wording in order to highlight the aspect of sustainability (which we see for MAR and reforestation, but not to RO).