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Hydrology and Earth System Sciences
Discussions

Interactive comment on "Groundwater fauna in an urban area: natural or affected?" *by* Fabien Koch et al.

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Dear referee,

we would like to thank you for your time and the constructive comments, which helped to improve the quality of the manuscript. Please find our detailed replies on the comments below. We hope that we answer all your remarks.

Referee #2:

This study on the distribution of groundwater fauna in the shallow subsurface of urban (city of Karlsruhe) and rural (nearby forest) areas, as well as the use of groundwater fauna for the assessment of the ecological status in groundwater has considerable scientific novelty. To my knowledge, this is the first study that investigates groundwater

ecological aspects in a city's subsurface. This strength by novelty, however, is kind of counteracted by serious weaknesses. While I like the study very much on one hand, it is a pity that the authors did not spend enough time to distill the best out of it. Besides obvious shortcomings in the study design (the selection of chemical parameters measured, the restriction to only well water), the authors did not dig at all into the data available in a 'statistical' sense. I do see more categories of land-use types. I think measures such as well depth and origin of groundwater (what if groundwater impacted in the urban area travels underneath the forest where it is sampled) would be interesting aspects to evaluate. Moreover, fauna data set comes along with further information that has not been used, i.e. the Shannon-Wiener biodiversity and the ratio of stygobites/stygophiles vs. stygoxenes. Not to talk about the determination of individual 'species' of Crustaceans and other groups of animals that could resolve the picture much more. Although, the basic water chemistry in the urban groundwater exhibits some differences to the groundwater sampled in the rural area, there is obviously no clear indication for a 'contamination' of the urban groundwater. An exception is only some temperature deviations. Thus, why it is expected that the groundwater fauna in the urban area is different. I would have loved to see a few hypotheses that are tested. When reading the preprint I also got the impression that most groups of groundwater fauna are described as quite temperature tolerant, however, other publications of the same authors claim the strong sensitivity of groundwater fauna upon groundwater warming. I really missed individual statistical testing of such questions. To be very honest, the paper addresses a really interesting topic that ghas ahrdly been studied to date but has not been properly prepared before submission. My feeling is also that some of the co-authors have not spend much time with the paper, otherwise it would not contain so many flaws. In the following, I will try to provide detailed comments that may help to improve the manuscript. Overall, I not sure if the paper, even when reworked properly, will satisfies the high standard of HESS.

Response: Thank you for the critical assessment of our study. We address your specific comments in more detail below.

Specific comments

Comment #1: P1 L19-20: How have the anthropogenic impacts be measured. I agree that elevated temperature may be seen as Impact. What else? The groundwater chemical analyses do not focus on any contaminants, with exception of nitrate; and nitrate concentrations are not elevated.

Response: We agree that our study is focusing on temperature and nitrate concentrations as important anthropogenic impacts on groundwater ecosystems. We now specifically mention these two proxies in the abstract and also cited the publication by Griebler et al. (2016) in the Introduction (see lines 76-78).

We are aware that there are more potential anthropogenic impacts, such as contaminants, which are not specifically considered in this study. We further agree that more investigations are necessary in the future, as there are likely to be more influencing factors on groundwater fauna distribution such as the sediment, groundwater flow, pollutants, nutrient supply, well design, etc. Thus, we added further research in the supplement of the manuscript and a short summary about what the urban impact is in the summary of chapter 3.1 (see comment #26 and comment #25 Referee #1).

Comment #2: P1 L21: it is mentioned here that more comprehensive assessment methods are required to fully capture the different effects on groundwater fauna. I agree. However, you should mention, at least in the discussion section, what you think of.

Response: We agree that potential strategies for more comprehensive assessment methods should be discussed in more detail. Hence, we added some information to the manuscript, which is also presented in the reply to comment #25 by Referee #1 and in the manuscript.

Comment #3: P2 L44-50: This paragraph does not seem to be linked to the what is introduced before and after.

Response: We agree. Hence, we linked the paragraph by adding the following introductory sentence (lines 44-45): “The availability of ecological criteria can only be increased by conducting a large number of studies dealing with the analyses of groundwater ecosystem health by investigating groundwater fauna.”

Comment #4: P2 L51: There is a pile of studies dealing exactly with that. You should name some as examples. What is really new with your study is that there is hardly anything investigated in urban areas.

Response: We agree. We reformulated the sentence and added some studies as follows: “Accordingly, stygobiotic biodiversity is still likely to be underestimated, although there are various studies on this topic (e.g. Gibert and Deharveng, 2002; Malard et al., 2002; Deharveng et al., 2009; Dole-Olivier et al., 2009a).”

Comment #5: P2 L53: Are you sure that the European Union (FP5) PASCALIS project focused on 7 North-American regions. Please check that again.

Response: We agree that the PASCALIS project is focusing on six European regions only. Gibert et al. (2009) focus on six European, as well as seven North-American regions. Thus, we deleted this part of the sentence.

Comment #5: P3 L57: If you state here that regional features have a stronger influence on groundwater fauna than local habitat features, you should test that with your data set. If this is true, maybe the anthropogenic impacts are not strong enough to overrule the regional selective forces. This point should also be discussed.

Response: We agree that this point should be tested with our data and discussed. Thus, we added the following information and results from an additional statistical analysis to this paragraph (lines 307-322), dealing with local habitat features:

“One important natural influence is the local geology, as fine sands and silts are typically rather harsh environments, resulting in an impoverishment of specific groundwater fauna such as Crustacea (Hahn, 1996). The city of Karlsruhe is located on carbonate

('Würm') gravel and river terrace sands, pervaded by bands of drifting sand and inland dune sands. These sediments are highly water-permeable and show almost exclusively vertical seepage water movement. Flood sediments (on top of the river gravel) and bog formations are located in the east and west of Karlsruhe (Regierungspräsidium Freiburg, 2019). This local geological limits the cavity size and therefore impacts the habitat of the groundwater fauna (Wirsing and Luz, 2007). For example, individuals of the genus Parastenocaris typically inhabit small-scale cavity systems (Spengler, 2017). Individuals of this genus can be found both in the wells drilled in gravel (4 wells) and in drifting sand sediments (3 wells) (abundance Parastenocaris vs. geological units: U = 216, p-value = 1.4×10-9). Amphipods are predominantly to be found in measurements wells located in the 'Würm' gravels (in 5 of 7 wells) (abundance Amphipoda vs. geological units: U = 180.5, p-value = 9.0×10-11). Moreover, it seems that differences in the geological units have an influence on the total amount of individuals (U = 1312.5, p-value = 1.7×10-9) and the relative amount of detritus (U = 476, p-value = 3.0×10-3). As these results show, regional geology has an influence on the occurrence of individual groundwater species and on the amount of individuals as well as on food supply. However, it is not possible to give a reliable estimate of the strength of the anthropogenic impacts, e.g. if they are strong enough to overrule the regional selective forces. Hence, this should be investigated in more detail in future studies."

Comment #6: P3 L83: you could also have used a different approach to look at your results. What if you treat the forest samples as your local natural reference? Just an idea. Starting from there, you could evaluate which well downtown Karlsruhe match natural conditions and which not. Currently, you obviously use a German-wide reference conditions and thresholds (Crustaceans >50%, worms <20%) that may not 'absolutely' reflect the situation in the natural surroundings of Karlsruhe.

Response: We fully agree that it might be useful to define local thresholds by using the forest samples. Thus, we tested the proposed idea. We used the average values of all wells in the forest to define local 'natural' conditions. The calculated values are as

follows:

Chemical: 8 mg/l O2, Nitrate: 2.7 mg/l

Physical: 10.7 °C, a high content of detritus

Faunistic: 28 % Oligochaetes, 66 % Crustaceans, 6 % other individuals, in average three taxa in each well, 131 individuals in each well, average Shannon Diversity Index: 0.7

The biggest issue with these conditions arises from the temperature (no well in the urban area is as cold as the wells in the forest) and the low nitrate concentrations in the forest. Without consideration of temperature and nitrate content, four wells in the urban area are in accordance with the new 'natural' reference values. As this number is similar to the original approach with the German-wide reference, it appears that these new thresholds cannot reflect the complex situation in the urban area of Karlsruhe. Thus, we decided not to adopt this idea for our paper.

Comment #7: In P3 L86: you say that the authors of the UBA study come to the conclusion that aquifer typology is more important than local features. Is this what you say? Why this is not properly discussed in your paper?

Response: We agree that this discussion is missing. Hence, we added a corresponding paragraph in the manuscript (lines 307-322, see comment #5 above).

Comment #8: P4 L113: If 56% of the city's area is covered by vegetation, doesn't it make sense to group the wells in the urban area according to their 'land type' on top and do some statistical analyses?

Response: We disagree to subdivide the wells in the urban area according to their land use due to the following reasons. The total city area of Karlsruhe contains not only the inner city centre and the neighbouring districts (termed "urban area" in this study), but also parts of the Hardtwald and several less built-up outskirts, which results in the high proportion of vegetation in the official 'city area'. The urban area itself however does

not contain enough green spaces to justify a more detailed subdivision and statistical analysis. In our opinion, there is a risk of over-interpreting the results by following this approach. Instead, sampling of groundwater fauna and parameter measurements should be repeated before more emphasis is put on other influencing factors, such as land use. To clarify the issue, we added the information about the definition of the city area in the manuscript (lines 117-118): "Based on the land use plan of Karlsruhe, about 20 % of the area of Karlsruhe (i.e. urban area, city centre, neighbouring districts, as well as parts of the Hardtwald forest and several outskirts), is covered by buildings."

Comment #9: P5 L127: It is mentioned here that the sampling took place between 2011 and 2014 and 39 wells have been sampled. But how often each well were sampled is not mentioned. Did I miss it. 3 times, as said in line 134? Or more often? You cannot have followed the recommendations of Hahn & Gutjahr published in 2014 when sampling took place between 2011 and 2014.

Response: We agree that this information is not mentioned explicitly, but would help to understand the framework of this study. We added this information in the part 'Material and sampling' (lines 141-143) and in Table S1 in the Supplements: "Every well is sampled at least three times. From 2011-2012, 22 measuring wells (mainly in the Hardtwald and the North-West of Karlsruhe) were sampled six times at an interval time of at least two months. In 2014, 17 measurement wells, mainly located in the south/inner city, were sampled three times."

Thus, our approach is in agreement with the recommendations given by Hahn and Gutjahr (2014).

Comment #10: P5 L134: what you mean with 'integrative sampling'? Explain!

Response: By "integrative sampling" we mean taking multiple samples repeatedly over a period of time. We agree that this explanation should be in the manuscript and therefore added this information (line 139).

Comment #11: P5 L136: replace 'groundwater ecology' by 'groundwater ecological status' ; we 'sampled' the fauna. . .

Response: We agree. Done.

Comment #12: P6 L145: If this table shall stay in the paper then the information provided with the individual groups of organisms asks for a balancing. The provided information is very heterogeneous. Some of the terms used have not been explained before, e.g. 'stygophile'.

Response: We agree that some terms are not explained before their use. Thus, we edited Table 1 and added a footnote, which explains the term 'stygophile' (see manuscript).

Comment #13: P7 L156: No, I do not agree at all. There is many natural groundwaters in good ecological shape that do not contain any dissolved oxygen, they may also produce ochre where they come in contact with oxygen. I guess we agree that these sites are not 'good' habitats for groundwater fauna. However, the absence of fauna does not necessarily mean a disturbed ecosystem status.

Response: We agree that the absence of fauna does not necessarily mean a disturbed ecosystem status. In our opinion, it is necessary to clarify that the ecological assessment takes place on the basis of groundwater fauna. Thus, we added the following sentences to Chapter 2.3 and edited the caption of Figure 1 in the manuscript: ". . .If an ecological assessment of groundwater ecosystems on the basis of the groundwater fauna takes place, some faunistic criteria have to be considered. Invertebrates avoid habitats that are ochred or have a low content of dissolved oxygen. Thus, unstressed or natural habitats are defined as. . .".

Comment #14: P7 L170: Doesn't it make sense to further categorize the land use types, also within the city limits?

Response: We disagree. In our opinion, a further subdivision is not reasonable. The

aim of this study is to give a first overview of the ecological groundwater conditions of the study area, so we decided to use only these two major categories (see also reply to the previous comment #8). Also, a subdivision of the urban area into “inner city” and “north-western city”, including industrial areas, in an earlier version of the study lead to similar results.

Comment #15: P9 L177: did you also consider well depth in your data analysis. It si a big difference between 8.5 and 39m below land surface which may affect occurrence of fauna and the availability of dissolved oxygen.

Response: We agree that the depth of wells can have an impact on the availability of dissolved oxygen and the occurrence of fauna. In our study, only two wells have a depth of over 16 m (in detail: 27 m and 39 m). The deepest well is uninhabited and has a content of dissolved oxygen of 0.97 mg/l. As the statistical analysis shows, the correlation between well depth and the total amount of individuals is not significant (U = 622.5, p-value = 1.7$\times$10-1), but there exists a correlation between the depth and content of dissolved oxygen in the wells (U = 1,478.5, p-value = <10-13). Thus, we added the following sentences in the Chapter ‘Physical and chemical parameters’ (lines 209-213):

“Moreover, it seems that with a greater depth of the measurement wells the content of dissolved oxygen is increasing (U = 1,478.5, p-value = <10-13). This can be explained by the fact that shallow wells can have a low water column, in which oxygen can rapidly be consumed by groundwater microorganisms, chemical reactions and/or groundwater fauna. In the upper unscreened part of deeper wells, dissolved oxygen can be consumed, while in the screened lower part oxygen is continuously refilled by oxic groundwater from the surrounding (Malard et al., 2002).”

This results shows that the content of dissolved oxygen depends on depth, but depth has no direct influence on groundwater fauna in this study.

Comment #16: P10 Figure3: why are there two lines (red and blue) indicading the

percentage of wells with good and affected ecological status? Automaticly one looks if the box is above or below. However, the values of the individual physicaö-chemical parameters are not in line with the ecological status. I recommend to delete the lines.

Response: We tend to agree. However, we would like to keep both lines and the important information given by these lines. Hence, we reformulated the caption of Figure 3 as follows: “Boxplots of the physical and chemical parameters for the forest and urban area in the study site and the proportion of wells in which ecological conditions are O.K. in percentage [%] indicated by the blue (forest area) and red (urban area) lines (secondary axis);. . .”

Comment #17: P10 L192: To my understanding, a concentration of 1 mg/L dissolved oxygen in wells water strongly indicates that there are anoxic conditions in groundwater. As is mentioned I the preprint well water is not representative for groundwater. To my opinion, since well water is open to the atmosphere, DO concentrations are likely to be overestimated. Gw fauna may, at times of elevated DO in groundwater migrate through the local subsurface and enter wells. There, they may outlast times of no oxygen in the surrounding aquifer. Frankly speaking, I am not sure if the threshold of 1mg/L of DO mentioned before should refer to the surrounding groundwater.

Response: We partially agree that the content of dissolved oxygen (DO) in the well could differ from the content in the surrounding groundwater. In our study, the water and the groundwater fauna are sampled in the well swamp. In the upper unscreened part of the well, DO can be consumed. The lower screened part of the well can be continuously refilled with oxic or anoxic groundwater of the surrounding (Malard et al., 2002). In addition, in the study by Hahn and Matzke (2005) and Korbel et al. (2017) hydro-chemical data such as temperature, pH and DO of the sampled well water and the surrounding groundwater shows no significant differences.

For these reasons, we assume that the content of DO, as wells as the threshold of 1 mg/l, of sampled well water in our study is also representative for the aquifer. Never-

theless, to clarify this issue we already added a paragraph (see comment #15) and the information in brackets '(temperature, pH, dissolved oxygen, etc.)' in the corresponding paragraph (Chapter 3.2 in the end).

Comment #18: P10 L198: The study does not show high nitrate concentration! When stating that $\leq$ 10 mg/L is natural, then in consequence nitrate concentrations between 1.3 and 14mg/l are not high!

Response: We agree. We therefore replaced 'high' by 'higher'.

Comment #19: P10 L199: In general, their relationship between DO and nitrate is not inversely correlated. Only when the oxygen is gone nitrate is reduced. As such, low or no oxygen goes along with low or no nitrate. I do not get the 'link' between oxygen and pollution claimed here (P10 L200).

Response: We agree that the relationship is not inversely correlated in general, and that the link between oxygen concentrations and pollution is not explained. Thus, we added the following sentences to the manuscript: "In the urban area average nitrate concentrations are generally higher and correlate with the content of dissolved oxygen (U = 278, p-value = 4.0$\times$10-3) showing the link between nitrate content and oxygen consumption. Wells with a content of dissolved oxygen below 1.5 mg/l have an average content of nitrate of 1.5 mg/l, caused by nitrate reduction under anoxic conditions. Groundwater with reducing conditions (< 5 mg/l dissolved oxygen) has an average nitrate content of about 7 mg/l in contrast to groundwater with oxidising conditions with 9 mg/l, which is characterised by the oxidation of ammonium to nitrate."

Moreover, we added the p-values (dissolved oxygen vs. nitrate concentration) for the forest area in the manuscript (line 217).

Comment #20: P10 L199: P11 L220: does this mean that Parastonocaris and Bathynellacea are 'type'-species (groups) for urban situations? Such a possibility is not discussed in the paper. There are groundwater ecology experts in the list of au-

thors. I miss an in depth interpretation of the ecological data.

Response: We partially agree that an in-depth interpretation of the ecological data is missing in the study. However, making a statement about a type species for urban areas on the basis of a single study area with a limited number of measurement wells does not seem reasonable. For this reason, we only hint at the possibility that these two species might be indicators of disturbed and stressed habitats.

Comment #21: P13 L231: Is it that stygobiont amphipods live predominantly within wells? This is to my opinion not a correct interpretation of what is published in Hahn & Matzke (Hahn is co-author of this preprint) and Korbel et al.

Response: We disagree that the interpretation is incorrect. In our opinion, the studies of Hahn and Matzke (2005) and Korbel et al. (2017) indicate that stygobiotic Amphipods have a habitat preference for open spaces, such as wells, and therefore can be found predominantly within wells. However, to eliminate any misunderstandings and in accordance with comment #18 of Referee # 1, we rewrote this sentence (see comment #18 Referee #1 and manuscript).

Comment #22: P13 L264: When the authors write about 'groundwater quality' it is not straightforward what is meant. Only very basic water chemistry (e.g. selected nutrients, pH, DO) and temp was measured. There is no indication for a 'bad' or 'impacted' groundwater quality (with the exception in temperature), so why should the groundwater fauna show associated distribution patterns.

Response: We agree that it is not straightforward what is meant by groundwater quality here. Therefore, we substitute the word 'groundwater quality' by 'groundwater chemistry' in this sentence. Also, we carefully checked the manuscript and clarified the differentiation between groundwater chemistry (i.e. chemical parameters) and groundwater quality.

Comment #23: P13 L235: Does the study of Brielmann et al. 2011 really state that

amphipods react sensitive to a gw temperature of 11 $\pm$ 5°C (which is natural gw temp in central Europe) or do they refer to a change of ambient gw temp by 11°C? Check that carefully.

Response: We agree that this sentence can be misinterpreted. Hence, we re-checked the literature and edited the sentence (line 264) carefully as follows: "Although, statistical analysis showed no clear correlation between the abundance of Amphipods and land use (U = 92.5, p-value = 1.5$\times$10-1), the higher number of individuals in the forest area could support the hypothesis that Amphipods indicate healthy groundwater ecosystems, as they react most sensitive to disturbances such as pollutants (Korbel and Hose, 2011) and groundwater temperature. In laboratory experiments with a thermal tank, Brielmann et al. (2011) found that 77 % of the individuals of the studied Amphipods (Niphargus inopinatus) preferred areas with a temperature between 8 and 16 °C. In addition, Spengler (2017) and Issartel et al. (2005) observed maximum temperatures up to 17 °C."

Comment #24: P14 L266: It would help the reader if you indicate the general groundwater direction in one of your maps (Fig. 2). If the groundwater flow direction in the area is north-west, then it is very likely that groundwater originating from the urban area is travelling below the forest. This point should be discussed as well.

Response: We agree. Hence, we indicate the groundwater flow direction in Figure 2. The groundwater flow direction in the study area is north-west towards the river Rhine.

Indeed, there is a certain likelihood that groundwater originating from the urban area can travel below the forest, although the whole area north-east in the forest area is water protection area. Nevertheless, the "Waldstadt" settlement in the north-east of the city might affect groundwater fauna in the forest area. Thus, we looked up measured chemical parameters of wells provided by the continuous monitoring program of the LUBW. One measurement well is located in the "Waldstadt", next to the wells T411 and T412 of this study. This well shows values in the range of the local background or

threshold of the drinking water ordinance of Germany.

Hence, to clarify this issue we added the following sentences (lines 230-231): "Moreover, no impact of groundwater originating from the urban area on the wells in the forest area is observed."

Comment #25: P14 L285: Why only the two criteria (>70% Crustaceans and <20% of oligochaetes were use for the evaluation of the ecological status. There are more criteria mentioned in the UBA report and in the international literature, some of which have been used or even developed by the co-authors, i.e. the Groundwater Fauna Index, the ratio of stygobites/stygophiles vs. stygoxenes, etc. Making use of these additional measures could provide a much clearer picture.

Response: We agree that using additional measures could provide more comprehensive information. Actually, we tested more methods during the preparation of this study, which we now present in the supplement of the manuscript.

The GFI however did not provide any additional information or valuable insights and was therefore excluded. The influence of multiple stressors, such as the pollution of the groundwater through industrial plants etc., and their effects on the governing parameters can bias the GFI. Moreover, under urban areas changes in GWT are caused by anthropogenic heat inputs (Menberg et al., 2013b, 2013a; Benz et al., 2014; Tissen et al., 2018), rather than being related to surface water influences. Hence, the GFI appears to be unsuitable for the assessment of the groundwater fauna in an urban setting. We added this information to the supplement of the manuscript.

We partially agree that use of the ratio of stygobites/stygophiles vs. stygoxenes is useful in the context of this study. We agree that this ratio will provide more information on the endemism of stygobiotic species. Yet, we decided not to use it, because the required determination of the fauna cannot be done by untrained persons, which was in the sense of the UBA project (Level 1). This information is therefore also not added to our manuscript. The same applies to the GHI, where the microbiological analyses

are beyond the purpose of a first tier assessment.

Comment #26: P15 L300-301: 'as expected, this indicates anthropogenically influenced groundwater ecosystems. . .'. Again, the physical-chemical data provided do not hint at a seriously 'impacted' groundwater quality. The only exception is the temperature. It would have been worth to expand the list of chemical parameters analyzed and include 'contaminants' besides nitrate which is more of an issue in agricultural land. I ask the authors to make clear in the paper 'what exactly the urban impact' is.

Response: We agree that the focus on nitrate and temperature as anthropogenic impacts in this study has to be clarified (see also reply to comment #1).

In order to expand the list of chemical parameters, we conducted further analysis using data provided by a continuous monitoring system. This information is now given in the supplement and a short summary is presented in chapter 3.1 (line 231-238): "Further investigations demonstrated that beside one larger and two smaller contaminated sites (however, still with concentrations below the threshold values, Figure S1), only minor groundwater pollution is documented beneath Karlsruhe (see Supplement). The chemical and physical parameters considered in the long-term monitoring system are within the range of local background and below threshold values of the drinking water ordinance of Germany (see Supplement for more information). In addition, groundwater fauna can usually cope well with short-term changes of chemical-physical parameters (Griebler et al., 2016). Previous studies showed that some species can even benefit from pollutants (Matzke, 2006; Zuurbier et al., 2013). Thus, the main documented impacts on groundwater quality in the study area are related to temperature and oxygen as well as nitrate concentration."

Comment #27: P15 L304-306: This sentence needs an explanation. Why do the results you obtained lead to the 'offer' of using groundwater for heating and cooling? This sentence is not in line with what has been discussed right before.

Response: We agree that this sentence needs further explanation. Thus, we rewrote

the sentence in the manuscript (lines 364-367) as follows: "This observed spatial heterogeneity in ecological conditions and the existing heat anomalies in the urban area also call for an adapted usage for shallow geothermal energy systems. Areas with no or only little groundwater fauna (i.e. affected habitats) could also be used to store thermal energy at higher temperatures. Thus, high-temperature aquifer thermal energy storage (HT-ATES) could be established in urban environments (e.g. Fleuchaus et al., 2018), where the demand is high."

Comment #28: Discussion section in general: I miss proposals for improvement, i.e. the use of additional parameters, more sampling, more wells, other sampling techniques (here I could find 1 sentence), . . .

Response: We agree. Done (see comment #1, #22 and #25 of Referee #1, see manuscript).

Technical comments

Comment #29: P1 L12: 'scarce' not 'scare'

Response: We agree. Done.

Comment #30: P1 L15: If I am correct, then the classification is from German Federal Environment Agency (UBA) but the result from a UBA funded research project. This makes an important difference. The funding agency not necessarily identifies itself with the outcome of funded projects. The 'invention' and 'responsibility' is with the authors from the study. As such, I would not call the scheme used, and UBA classification scheme. Same applies to P2 L31.

Response: We agree. Done. "For classification we apply the scheme of Griebler et al. (2014), on behalf of the Federal Environmental Agency (UBA),. . ."

Comment #31: P1 L16: wrong wording: 'fine' ecological conditions. Replace by 'good', 'natural' or something similar. Best you use the terminology used with the assessment scheme you used.

Response: We agree. Done.

Comment #32: P2 L26: HESS is an international journal. I would cite 'German' and 'grey' literature only if there is not similar publication in international journals. This is my very personal opinion.

Response: We agree. However, as the study site is located in Germany, it is sometimes necessary to cite 'German' literature, e.g. to get data on regional geology, which is often not available in the international literature. We carefully assessed the cited literature again and found that the mentioned study cannot be replaced and is thus kept in the manuscript.

Comment #33: P2 L28: 'retention' is the wrong term here! What you mean is 'degradation' or 'mineralization'.

Response: We disagree. We mean retention of organic matter by groundwater ecosystems, which react like a buffer and storage zones.

Comment #34: P2 L30: delete 'valuable'. What do you mean with 'tied'? Reword.

Response: We agree. Done. We mean "to bind", e.g. organic matter, by biological processes/microbial activity. For a better understanding 'tied' is replaced by 'bound'.

Comment #35: P2 L34: change 'relatively' to 'typically' or 'naturally'. Typo: Brielmann et al. 2011 not 20011.

Response: We agree. Done.

Comment #36: P2 L35: change âAËŸŽstygobiote' to âAËŸŽstygobite' or 'stygobiont'.

Response: We agree. Done, 'stygobiote' is replaced by 'stygobiont'

Comment #37: P2 L38: . . . groundwater . . . is not yet recognized as a protected habitat . . . reword this part of the sentence. Wat you probably mean is that gw is not yet recognized as an ecosystem that deserves protection.

Response: We agree. Done.

"Nevertheless, groundwater is not yet recognized as a habitat, which is worthy of protection, in German and European legislations."

Comment #38: P2 L39: change 'assessing groundwater ecology' into ' assessing groundwater ecological status'.

Response: We agree. Done.

Comment #39: P3 L59: delete 'Unfortunately'. Not needed.

Response: We agree. Done.

Comment #40: P3 L65: do the temp fluctuations range between 4°C and 20°C or is there a temp fluctuation with a temp range between 4°C and 20°C. Try to be more precise with your wording.

Response: We agree. We have rewritten the sentence: "According to Brielmann et al. (2011) annual temperature fluctuations in aquifers, caused by shallow geothermal energy systems, range between under 4 °C in winter and up to 20 °C in summer."

Comment #41: P3 L73: change 'clearly increasing' to 'increased and 'usually decreases' to 'decreased'.

Response: We agree. Done.

Comment #42: P3 L75: Brielmann et al. 2011 not 20011!

Response: We agree. Done.

Comment #43: P3 L79: The UBA did not develop anything! The UBA funded a research project in which these tools you refer to were developed. Rephrase this sentence.

Response: We agree. Hence, we rephrased this sentence: "Commissioned by the Federal Environmental Agency of Germany (Umweltbundesamt, UBA), Griebler et al.

(2014) developed a concept for an ecologically based assessment scheme for groundwater ecosystems."

Comment #44: P4 L96: change 'waterside filtration' to 'river bank filtration'.

Response: We agree. Done.

Comment #45: P4 L98: 'beneath' an urban area

Response: We agree. Done.

Comment #46: P4 L99: you can not sample thermal properties. You collected or sampled gw fauna and 'analyzed' gw chemistry and measured gw temp.

Response: We agree. Thus, we rewrote the sentence: "Hence, in 39 groundwater monitoring wells in Karlsruhe, Germany, the groundwater fauna is sampled, groundwater temperatures are measured and chemical properties are analysed."

Comment #47: P4 L100: Again, it is not the classification scheme of the UBA.

Response: We agree. Thus, we rewrote the sentence: "In our study the classification scheme developed by Griebler et al. (2014) is applied."

Comment #48: P4 L101: 'state of ecosystem quality' sounds weird.

Response: We agree. Thus, we replaced 'state of their ecosystem quality' by 'the quality of their ecosystem'

Comment #49: P4 L116-117: annual mean LST! Is this what you mean?

Response: We agree. We mean annual mean land surface temperature (LST). Thus, we added 'annual mean'.

Comment #50: P4 L120: Didn't you specifically 'analyze' statistically if wells in the area of known contaminations show different features than others?

Response: We partially agree. Wells in the area of known contaminations can indeed

show different features than others, yet in this study only two measurement wells are close to a known contamination, which makes a statistical analysis infeasible. Hence, we added some information in the manuscript (see our reply to comment #26).

Comment #51: P7 L149: . . .classification scheme in the framework of a research project funded by the. . .

Response: We agree. Done.

Comment #52: P7 L152: O.K. is an improper term in this connection

Response: We agree, but we would like to keep the original phrase and meaning of the original document by Griebler et al. (2014).

Comment #53: P11 L207: chemical characteristics do not distribute! There is distribution patterns.

Response: We agree. Done.

Comment #54: P13 L242: 'Larger'!

Response: We agree. Done.

Comment #55: P13 L252: 8.3 mg/l is 'not' a rather high nitrate content! Same applies to P13 L257.

Response: We agree. Thus, we reformulated the sentence:

". . .and a rather high nitrate content (8.3 mg/l) compared to the wells in the forest area. . ."

". . .and nitrate concentrations up to 14 mg/l, which is above the geogenic concentration of 10 mg/l and higher compared to the wells in the forest area."

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Please also note the supplement to this comment:
https://hess.copernicus.org/preprints/hess-2020-151/hess-2020-151-AC2-supplement.pdf

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