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Hydrology and Earth System Sciences
Discussions

Interactive comment on "Impact of climate change on groundwater in a confined Mediterranean aquifer" *by* Y. Caballero and B. Ladouche

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Note for the authors and editor

The following review was written by a student of the MSc programme Earth and Environment at Wageningen University. As part of the course Integrated Topics in Earth and Environment, students are asked to prepare a review of a scientific paper. The supervisor of this review process is Ryan Teuling. The manuscript by Caballero and Ladouche was one of the manuscripts that was selected for this exercise. The review is written as an official review in order to comply with the course guidelines, but it should be considered by the authors as a regular comment which they can use to improve the manuscript. I hope that this comment will positively contribute to the review process

and that it will help the authors to improve their manuscript for possible publication in HESS.

The manuscript by Caballero and Ladouche entitled Impact of climate change on groundwater in a confined Mediterranean aquifer deals with the contribution of climate and pumping forcing to piezometric variation. Inverse modelling based on wavelet analysis was used to simulate groundwater dynamics. This was done for two piezometers representative for the study area. Both the temporal variation and the vulnerability to climate change and pumping were investigated and quantified. The authors state that an alternative approach is necessary for determining the piezometric variation since hydrodynamic models make use of detailed descriptions of the geometry and hydraulic properties, which are rather difficult to acquire given the heterogeneity in various sedimentary units. Therefore a numerical relation between climate, pumping and groundwater variation was used for the analysis. The results show that pumping is the main factor controlling drawdown of the water table. This leads to the conclusion that the aquifer in the Argelés area is relatively invulnerable to climate change.

Though in recent years the effect of climate change on groundwater resources is studied more frequently, the majority of literature is aimed at the impacts on surface water (Green et al., 2011). Given the fact that knowledge on the impacts of climate change on groundwater resources is rather restricted, especially in case of confined aquifers, research on this topic is necessary. Besides, the lack of data makes it difficult to quantify the groundwater change (IPCC, 2007a). Existing studies take a range of approaches, ranging from statistical models (Yang et al., 2005) to more complex three-dimensional groundwater flow models (Scibek and Allen, 2006). Brouyère et al. (2004) also used a more complex, physically based model to simulate the response of groundwater to climate change in a chalky aquifer in Belgium and found decreasing groundwater levels. In addition, Ali et al. (2012) studied the effect of climate change on groundwater resources in Australia and concluded that confined systems are less sensitive to climate change than unconfined systems. This paper presents an alternative approach

to study the variation of groundwater levels due to climate change and therefore it provides a welcome addition to existing studies.

Overall the research is interesting. It is innovative because of the new approach that was taken to study the effect of climate change on confined aquifers. Moreover, it contributes to an important issue, since pumping can be related to future water demand; especially in dry climates where the demand is expected to increase significantly. Considering this, the research shows potential to advance science. However, there are some limitations that require additional research. Therefore, I listed a few points of interest, which I believe deserve some attention. Overall I recommend some minor revision before this paper can be published.

Major issues

The first point of criticism deals with the title. In addition to climate change the paper puts quite some emphasis on the effect of pumping on piezometric variation. A considerable part of the research is about investigating and explaining the seasonal and permanent trend of pumping. This also appears from the following example:

“The model was constructed on the assumption that the long-term trend is fully explained by the signal of permanent pumping.” (page 10129, line 22-24)

The first question that rises is: why would the model be constructed in such a way that the long-term trend is explained by the permanent pumping rather than climate change? The title namely suggests that climate change is the aspect to be studied. This implies either the modelling approach is not correct or the title is formulated incorrectly, given the fact that the effect of pumping is not explicitly mentioned. To me, here, the latter case seems more reasonable and if pumping indeed is the dominant process in controlling the hydraulic head, it should be included in the title. This could result in one of the following titles:

“Impact of climate change on groundwater and the implications for pumping in a con-

fined Mediterranean aquifer”

Or:

“Impacts of both climate change and pumping on groundwater in a confined Mediterranean aquifer”

Secondly, long-term trends, such as climate variability, can be modelled with less sophisticated techniques than wavelet analysis. Simple regression methods, as linear regression for example, are common tools to determine long year trends. This tool is applied in several reports of the IPCC, including the edition published in 2013. The strength of wavelet analysis is detecting dominant modes of variability (Torrence and Compo, 1998). Hence, for pumping and short term climate variability it might be an appropriate method to get more insight in the effects of these factors on the hydraulic head, but for long-term trends it does not show distinct benefits compared to linear regression . This is supported by the high values found for the Nash criterion of the model. However, the modes rather than the long-term trend are responsible for the high values.

Though, the approach itself is not incorrect, my suggestion is to use a less complex method that is easier to understand and aimed at the long-term trend. This makes the research less innovative, but easier to read. So I would recommend an alternative approach like linear regression to study the effect of climate change on piezometric variation. Although, for the effect of pumping the wavelet analysis could still be used.

Considering climate change in coastal areas saline intrusion is quite an important issue, because it forms a potential threat to the water resources in those regions (Post, 2005 and FitzGerald et al., 2008). So, when studying the effect of climate change on coastal aquifers, this aspect cannot simply be neglected. In particular because this research is aimed at climate change in coastal regions as well as pumping. Ferguson and Gleeson (2012) showed that coastal aquifers are more vulnerable to groundwater extraction. The conclusion of this research that the aquifer is relatively invulnerable to

climate change is in my opinion a bit premature. Therefore, detailed simulations on saline intrusion are required. As there are several studies (Masterson and Garabedian, 2007, Webb and Howard, 2011, Loáciga et al., 2012) that predict the negative impacts, the methods are thus available, which makes incorporating this aspect into the research less time-consuming.

Minor issues

Regarding the methodology I have one less extensive, final remark. The methods is quite extensive and at some points rather complicated, which makes thorough understanding of the methodology hard. For example, not all of the readers are experts in wavelet analysis. Therefore some basic principles of wavelet analysis should be included. Though, the structure in the form of separate sections is very clear. Furthermore, the authors put a lot of effort in providing the readers from sufficient information. However, the overview on how one method is linked to the other is lacking.

Specific comments

In general the writing style is good, since the paper is easy to read. The use of the apostrophe (e.g. on page 10115, line 5 and page 10121, line 21) is sometimes a bit confusing, especially in long sentences, so try to avoid excessive use of it. Besides, the following sentences are difficult to read or contain mistakes, including typing errors, and should therefore be edited:

- Page 10110, line 18: “models that make use of ” instead of “employing”.

- Page 10111, line 16-18: “challenging enough to prevent” should be replaced by “may be quite challenging and in such cases the use of hydrodynamic models should be prevented.”.

- Page 10114, line 23: “representative of that of” should be “representative for”.

- Page 10115, line 1: “Two piezometers” should be removed.

- Page 10115, line 14: “that are” is missing between “operations” and “likely”.

- Page 10116, line 9: “to” can be removed.

- Page 10119, line 1: “to characterize” instead of “to characterizing”.

- Page 10119, line 23: “river contribution” should be “the contribution of the river”.

- Page 10120, line 10: “Rs(t) and Rs (t)” should be “Rs (t) and Rf (t)”.

- Page 10120, line 15: “values” should be “value”.

- Page 10121, line 24: “to be able” instead of “as”.

- Page 10122, line 14: “2040-60” instead of “2040060”.

- Page 10126, line 23: “the” in front of “spring” can be removed; this also applies to the other seasons mentioned.

- Page 10130, line 5: “was” instead of “were”.

- Page 10134 and 10138-10139: The references of Aunay and Pinault should be listed in chronological order.

Figures

- Figure 2: Colours would make the figure easier to understand and distinguish between series, since now it is hard to make a distinction between the different lines. Furthermore, for clarity it would be useful to indicate that with 10912x0024/F the piezometers are meant.

- Figure 3: The circles are not good visible, again the use of colours could be helpful. Besides, there is a typing error on the y-axis of the figure: “Pumpig” should be “Pumping”. Finally, the graph does not look like a cumulative plot, since cumulative plots in general increase.

- Figure 8: On the y-axis of the upper panel “cumulative” is missing.

- Figure 13: Additional headings above each panel would make this figure easier to interpret.

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