Review: “Regionalisation of groundwater droughts using hydrograph classification” by Bloomfield et al., HESSD 2015

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General comments

The paper presents a regional analysis of groundwater droughts based on a regional data set from Lincolnshire, UK. The scope of the paper is to present and apply a method to regionalize and quantify groundwater drought. The overall question is whether differences in the ground water signals can be attributed to precipitation input or to catchment and aquifer properties.

The approach uses cluster analysis to form groups of groundwater gauges which are homogeneous in terms of the temporal signal of the standardised groundwater index. The characteristics of the so-obtained clusters are assessed with respect to drought duration and magnitude, and the temporal characteristics are assessed with respect to correlation length obtained from correlograms. It is shown that clusters differ in their groundwater characteristics, and they are correlated to SPI with different accumulation length, but do not relate on precipitation characteristics which are uniform for the study area.

The study is novel in the sense that it is one of the first studies focusing on a regional analysis of groundwater droughts based on observed time series, and therefore addresses very relevant scientific questions within the scope of HESS. The paper is well written in the sense that it is easy to follow any step of the analysis, and doing so is exciting. The analysis methods used are cluster analysis and correlograms which are rather standard, but in the proposed combination very effective to perform the regional analysis. The results yield interesting insights into controls of groundwater droughts in general, and specifically for three major drought events analysed.

However, the presentation of the study can generally be improved to sharpen the scientific level of presentation. The title and abstract do not optimally reflect the study content (I think the term regionalisation is misleading as no model for regional estimates is established). Further, the abstract can be improved to better reflect the scope, methods and results of the study. The same applies for the structure of the paper (notably, results contain a lot of discussion, and the discussion section is not quite significant, and does not put the findings into context of existing literature), which could be more stringent. I therefore suggest moderate revisions to make the paper more concise and clear, and more useful for the reader.

Specific comments

Title:
The title should be modified to better reflect the content of this paper.
(The term regionalisation is misleading as the focus is not to establish a model to predict droughts in space from gauged sites, which is the main purpose of regionalisation.)
A possible title would be „ Regional analysis of groundwater droughts using hydrograph classification”

Sub-section titles (section 4-5) are generally not sharp descriptions of their content. Consider revising some of them. Try to avoid unnecessary details.

Abstract:
Also the abstract should be sharpened to transport main messages in a concise way.
E.G. *The categorisation scheme uses non-hierarchical k-means cluster analysis.*
→Reformulate so that the reader knows what data are clustered.
For each cluster a correlation can be established between the mean SGI and a mean Standardised Precipitation Index (SPI) associated with an optimal SPI accumulation period, q_{max}. Avoid abbreviations in the abstract. Rather, state that SPI is associated with different accumulation periods.
Based on a comparison of SPI time series for each cluster and SPI estimated for the whole study area, it is inferred that the clusters are largely independent of heterogeneity in the diving meteorology across the study region and are primarily a function of catchment and hydrogeological factors. Difficult to understand. (ASO)
5295 line 3: This was already said before

1 Introduction
5295: line 10-15 and line 23-26: Such huge and unspecific citation blocks are not useful for the reader. Either discuss specific messages of each citation, or reduce to 1-2 main references.

3 Data and methods
Section 3.2.2, line 5305
a) what is the ... distance BETWEEN time series. Does this mean that each month is a variable?
b) why a different measure is used here as in the hierarchical CA?

4 Results

5312 Section 4.4 heading

The use of the term "regionalised" is a bit vague. Does this mean "by region" or "of the "mean regional" signal instead of individual signals?

(I would say that the term "regionalisation" goes further than just a regional view, and includes a regionalisation model to bring the information of data points into space. In your case, the regionalisation model is the regional mean SGI / SPI based on hydrograph clustering.)

5312 Line 17:

… following the convention of McKee et al. (1993), negative values of SGI denote drought conditions:
This definition is different to the more recent WMO convention which refers to a drought event when " the SPI is continuously negative and reaches an intensity of -1.0 or less." whereas "negative values (simply) indicate less than median precipitation", and are classified as "near normal". I am advocating to call only events with abnormally dry conditions a drought, and suggest that this difference should at least be clarified in the paper.

Reference: World Meteorological Organization, 2012: Standardized Precipitation Index User Guide (M. Svoboda, M. Hayes and D. Wood). (WMO-No. 1090), Geneva.

5313 line 12: I would hesitate to postulate a linear relationship from Figure 10 which is valid over all clusters (e.g the patter n from CL2 looks quite nonlinear). What I can see is a strong correlation. (In a similar way replace in heading of Figure 10 "as a function" by something like "versus" to reflect that there is no directional, causal relationship between duration and magnitude.

5314 line 20: This is not shown in Figure 11...

Think that all interpretations of temporal patterns for the 3 drought events are based on Figure 5 and 6 – please indicate this in the text.

5315 line 18ff: In contrast, however, we have shown the expected lagging of multi-annual groundwater droughts behind meteorological droughts is not evident in the present study. Can you say this, based on a comparison with a log-term aggregate of precipitation (SPI_12)? I would expect that there will indeed be a time lag, but it is already filtered out by the long aggregation scale chosen to reach maximum correlation of SPI and SGI…

5 Discussion and conclusions

I find the whole discussion section not informative and not at the required standard of reflecting the methods and findings of this study in the light of existing literature. In detail:

5.1 The regionalisation of groundwater droughts: the title is very general, not informative.

The first two paragraphs do not contain interesting material and can be deleted. E.g, 2nd paragraph, the statement of using different CA is really basic and was an initial statement in the methods section.

3rd paragraph "The *k*-means clustering has been performed on the complete SGI hydrographs" – OK. Also 4th paragraph.

Section 5.2 Implications for monitoring groundwater drought

It has been shown that there can be pronounced differences in the characteristics of multi-annual drought episodes between aquifers within a region (Fig. 9).
This is opposed to the message of Fig. 9 as delivered on p. 5310 that time-series are coherent within the clusters. As the whole paragraph does not really transport new findings of this study I suggest to delete it without a significant loss of information.

I noticed that there was much more elements of discussion in section 4, which could be transferred to section 5 E.g. half of section 4.4 is a discussion of the event analysis of this paper in the light of literature and this part may move to section 5. (starting with p 5315 line 10). And the whole section 4.5 could move to the discussions.

Conclusions: Suggest to have them in a separate section, and in conventional continuous text form rather than bullet points.

Tables

Table 1 and 2: All symbols used in the table should be explained in the heading.

Figures

Use consistent referencing style to figures throughout the text (currently Fig. and Figure are used).

Figure 3: colours light blue and yellow should be flipped to make colour coding more similar to (b).

Figure 5,6,7: The presentation of these figures in the text is not in a logical order:
5308, Line16-19: Here figures are introduced but not discussed, could be deleted
Figure 7 should be presented before current Figures 6, and perhaps 6 before 5.
Please adapt the text on pages 5308 – 5309 accordingly.

Figure 6: heading: replace *respective qmax values* by "different aggregation periods qmax"

- Each panel: I would like to read the aggregation period in the plot, eg. SPI_16...

Figure 9: Suggest to flip the colours in the left panel so that dry states are marked with redish colour and wet states in blue, as this is more intuitive.

Figure 10: In heading, replace *as a function* by "versus" or "by" (“as a function would make one think of a directional/causal relationship from X on Y which is not the case as both variables are simply aspects of drought events.)

Minor, technical comments

Egu. (2) g0 needs be defined

5306 line 18: replace co-efficient with coefficient

5307 line5: have instead of has?