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Hydrology and Earth System Sciences
Discussions

Interactive comment on "Characterizing the spatiotemporal variability of groundwater levels of alluvial aquifers in different settings using drought indices" *by* J. C. Haas and S. Brink

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The manuscript aims to improve the understanding how aquifers in different alluvial settings respond to extreme events through the use of standardized time series of groundwater levels (SGI), precipitation (SPI), and river stages (SRSI) for three study areas within the river Mur river basin. Using correlation matrices to visualize results, differences and similarities of the study areas are discussed.

General Comments: I am impressed by the richness of the groundwater level data in this region, and that is used in the manuscript. Also, I enjoyed learning about the area. The paper presents a novel way to view water level correlations to each other, and physical drivers via SPI and SRSI, for potentially understanding aquifer responses

to extreme events, human influences, and provides potential to gain insight of aquifer properties.

One of my main concerns is that the correlation matrix figures, which are the primary results figures, are extremely hard to interpret given the current figure symbology, and figure discussion. There should be very clear descriptions given on how to interpret these figures when introduced, and also more during figure interpretation and discussion when detailing results.

I am disappointed that the words hydraulic conductivity, transmissivity, or permeability, are not found in the paper, nor are there discussions on how these aquifer properties (and aquifer storage) influence the results. It is recommended that the authors relate the results to aquifer properties. If property information is no available, then it is suggested that proxies and generalized properties should be used to make the results and conclusions more complete.

Monthly correlations for different time scales of SPI were not considered, which could show additional details on recharge, discharge, and surface and groundwater interactions. Authors should consider the addition of monthly correlations similar to methods presented in references pointed out in specific comments.

Perhaps the addition of a discussion on how a combination of modeling and this approach could be used to calibrate and better understand the human / landuse / pumping impacts surface and groundwater interactions might be a good addition.

Specific Comments

-Many paragraphs are small/one sentence paragraphs. These should be combined together.

-Page 1; line 1. Suggest adding "of" in "To improve the understanding (of) how aquifers.."

-Precipitation measurements collected in valley bottoms, and assumed uniform over

each sub basin. What about spatial and temporal aspects of this assumption? Please mention.

-Page 6; line 24. “While there is some criticism of the gamma distribution (see e.g. Guttman (1999)), it is generally a widely used and recommended mended index (see e.g. Svoboda et al. (2012)).”

Good point - there have been quite a few questions raised lately about issues of the SPI’s assumed gamma distribution assumption – perhaps cite this new one and discuss – and if these findings perhaps influence yours.

Blain, G. C., & Meschiatti, M. C. (2015). Inadequacy of the gamma distribution to calculate the Standardized Precipitation Index.ÂăRevista Brasileira de Engenharia Agrícola e Ambiental,Âă19(12), 1129-1135. http://www.scielo.br/scielo.php?pid=S1415-43662015001201129&script=sci_arttext

-Page 3; line 8. “For these three subregions monthly groundwater levels as well as river stages and precipitation are available at a the ehyd.gv.at website (BMLFUW, 2016).”

How are groundwater levels measured – steel tape, e-tapes, pressure transducers? What type of precipitation data (i.e. snow, rain, both), and how is it measurements? Please provide more background and details. Very impressive that all this historical data exists, but more background would be great to get a better picture of how it is done and perhaps other agencies can adopt.

-Page 8; line 10. “For each possible combination of standardized wells (SGI), standardized precipitation (SPI) or standardized river stages (SRSI) a Pearson Correlation coefficient was calculated. In order to facilitate the comparison of standardized groundwater levels, river stages, and precipitation within the individual subregions, the correlations between the indices have been plotted within a matrix, showing all the groundwater monitoring wells, all the river stages and SPI1, 3, 6, 9 and 12 for each subregion, similar to the matrices applied in Stoll et al. (2011) and Loon and Laaha

(2015).”

More details need to be discussed so the reader can get a better understanding of the matrix plots – like “for example, along the x-axis is …. where each cell represents a different …” etc.. Perhaps follow the descriptions by Stoll and Loon and Laaha to provide further explanations.

-Page 8; line 16 – “According to Vekerdy and Meijerink (1998), correlations between daily river stages and groundwater levels in distances similar to those relevant for this paper are mostly below 30 days. Likewise, Bloomfield and Marchant (2013) as well as Kumar et al. (2016) found with few exceptions the highest correlation between SGI and SPI associated with a time lag of zero months. As this is particularly expected in shallow alluvial aquifers, only Pearson Correlation coefficients without a time lag are considered here.”

For all wells? Did you explore if optimal time scales were greater than or less than 1 month? This would be a fairly easy thing to explore, especially put into context of well distance from the stream, etc. Presenting correlations without time lags seems odd.

-Figure 2. This is really complex to interpret. Is there any additional labeling / symbology that could help? For example I count 5 boxes under the SPI 1-12, and SPSI has 3 boxes. Can you help the reader interpret the figure better? For example the diagonal – can you tell the reader what this means? What do the “bulls eyes” correlation features represent? The figure caption should be pretty self-descriptive, so this one could be long – or integrated into text.

-Page 10; line 6. “Most wells outside of the core of this region show a similar behavior, resulting in an average Pearson correlation coefficient of all of these wells with each other of 0.59. These wells show a low correlation with the SPI1 and moderate to high correlations with the longer SPI averaging periods, as expected from the previous literature (Bloomfield and Marchant, 2013; Kumar et al., 2016).”

Perhaps add that this is to be expected since these wells are further away?

-Page 11; line 6. The wells from the deeper aquifer also show a clear increase in correlation with an increase in the length of the SPI averaging periods, starting with an average correlation of the wells with the SPI1 of -0.04, reaching a maximum correlation of 0.38 with the SPI12, which is significantly lower than the correlations seen in the shallow wells. The average correlations of the deeper wells with the rivers range from -0.13 with the local Pöls to 0.24 with the downstream Mur.

Which deep well/labels should the reader be looking at exactly in Figure 2 to see this longer / smoother water level signal?

-Page 11; line 11. "The rivers are correlated well with each other, indicating a similar flow regime in the upstream and downstream Mur, as well as in the tributary Pöls, but the correlations with the precipitation are low to moderate, ranging form an average of 0.27 with SPI1 to 0.48 with SPI6."

-Perhaps the low correlation is the assumption of a standardized time scale of 0 months for stream stage?

Can you describe the impact of snow accumulation and melt, and possible lag times in this statement?

See McEvoy et al. (2012) and Abatzoglou et al. (2014) on evaluating precipitation and streamflow indices for different time scales.

McEvoy, D. J., Huntington, J. L., Abatzoglou, J. T., & Edwards, L. M. (2012). An evaluation of multiscalar drought indices in Nevada and Eastern California.ÂăEarth Interactions,Âă16(18), 1-18.

Abatzoglou, J. T., Barbero, R., Wolf, J. W., & Holden, Z. A. (2014). Tracking interannual streamflow variability with drought indices in the US Pacific Northwest.ÂăJournal of Hydrometeorology,Âă15(5), 1900-1912.

-Page 12; line 1. "Surprisingly, some of the wells closest to the Mur on both sides of the river are not very well correlated with each other and are also not among the wells with highest correlations with the rivers."

Is this due to differences depth of well screen intervals / depths? Please explain.

-Page 12; Line 14. "Well MKr is located closest to the river Mur, yet it shows no high correlation with it."

Why is this? What is the well depth of MKr? Can you tell the reader what your idea is about why this is?

-Page 12; line 18. "The rivers are very highly correlated with each other, but only show some minor correlations with the 3 and 6 month SPI with average correlation coefficients of 0.38 and 0.39."

Perhaps because monthly correlations were not considered? See figures 9 and 10 and respective discussions in McEvoy et al. (2012) for some ideas to further describe why correlations were low, or if analyzed a different way, may increase. https://www.researchgate.net/publication/236687241_An_Evaluation_of_Multi-scalar_Drought_Indices_in_Nevada_and_Eastern_California

-Page 16; line 2. "Figure 4 shows the development of the three subregions when split-up into time periods of 12 years."

How so? Please further explain figure 4 to this point.

-Page 17; line 29. "At high water levels, the river feeds the groundwater, thus superpositioning its signal onto the groundwater, whereas the groundwater provides the river baseflow in low water conditions, thus giving the river a groundwater signal at low water levels."

Can you show this point with the standardized time series? It is not clear from the correlation matrix plots. What is the "groundwater signal at low water levels." Is there a

“signal” during this condition?

-Page 18; line 25 – suggest using the term groundwater discharge rather than groundwater runoff.

-Figure 5. What time scale are the SPI values – 0 month? Please specify.

-Figure 5 and 6. Why not use 48 or 60 month time scales for SGI, SPI, and SRSI rather than using a 0 month and then smooth using a 5 year moving average of the indices? Seems a bit odd and misses the point of the use of multi-temporal time scale indices. Please explain.

-Page 22; line 4 – change hydro(geo)ology to hydrogeology. Also, it is not agreed that the “general consensus is that hydrogeology is stationarity.” Milly et al., 2008 states that stationarity it is dead – but that in water management stationarity is often assumed. . . this is not the same as a “general consensus in hydrogeology seems to be the assumption of stationarity” as stated - please revise.

-Page 24; line 3. “It was shown that the correlation matrix approach enables a quick visualization and comparison of different locations and time spans and that standardized indices, such as the SPI, the SGI and the SRSI (SGI applied to river levels), allow for a thorough comparison of groundwater wells, rivers and precipitation.”

More thorough labeling and discussion on how to interpret the matrix plots when they are introduced, and during results discussion is needed for these plots to “enable a quick visualization and comparison of different locations and time spans” – please provide more details to help the reader digest these plots.

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