Proc. of the 5th IAHR Europe Congress — New Challenges in Hydraulic Research and Engineering
Editor(s) Aronne Armanini and Elena Nucci
doi:10.3850/978-981-11-2731-1_305-cd

Effect of climate change on the groundwater levels: evaluation of local changes as a function of antecedent precipitation indices

V. Todaro, M. D'Oria & M. G. Tanda
University of Parma, Italy

ABSTRACT

The first purpose of the present study is to analyze the relationship between observed groundwater levels and two drought indices in an historical period. The second purpose is to predict the variation of groundwater level due to climate change.

INTRODUCTION

Groundwater represents a precious resource, especially in the critical period of the years when the surface flows are of very low quality and the need of water supply increases. Therefore, the analysis of the groundwater level response to climate change is essential and the discussion on this topic is increasing in the recent scientific literature.

Groundwater levels depend on many factors such as the geological formation, the anthropogenic influences, etc. Due to the difficulties to quantify these elements, it is challenging to evaluate the effects of climate change on these important aspects. We try to apply a simple statistical approach to analyses the variation of groundwater level, in a certain number of wells, as a function of two simple drought indices: the Standardized Precipitation Index (SPI), and the Standardized Precipitation Evapotranspiration Index (SPEI). SPI [3] is a multiscale index that defines droughts as a function of only precipitation data. SPEI [4] is analogous to the SPI, but describes droughts in terms of temperature and precipitation.

The aim of our study is to investigate if a good correlation exists between the groundwater level and the drought indices and, in positive case, to apply the same correlation to future climate projections; this is a novelty with respect to previous works. The future drought indices were computed according to 13 EURO-CORDEX [2] Regional Climate Model (RCM) results, under two Representative Concentration Pathways (RCP): RCP 4.5 and RCP 8.5. The groundwater levels, in the different monitoring wells, were forecasted up to 2100.

DATA AND METHODS

The study area involves the basins of the Parma, Taro and Enza rivers, in Northern Italy. We used the well data available from the Regional Environmental Agency (ARPAE); 24 wells were selected based on the data abundance in the monitoring years 1976-2017. The monthly groundwater levels in the spring season, which present minimal anthropogenic influences such as pumping and irrigation, were chosen for the analysis.

The historical precipitation and temperature data (available from ARPAE) were collected for 15 rain gauges from 1917 to 2017 and 4 temperature stations in the period 1976-2017.

The SPI and SPEI were calculated at the time scales of 3, 6, 9, 12, 18, 24 and 36 months; the potential evapotranspiration was calculated according to the Thornthwaite (1948) equation.

After the estimation of the drought indices in the period 1917-2017 for the SPI and 1976-2017 for the SPEI, we analyzed the Pearson correlation coefficient between the groundwater levels at a well and the indices at different time scales. For the wells presenting correlation coefficients greater than 0.7 (5% confidence level) we fitted a linear relationship. The same regression coefficients were used to compute the future groundwater levels according to the forecasted drought indices (SPI and SPEI).

The future precipitation and temperature data, used for the computation of the SPI and SPEI, were extracted from the 13 RCMs for three time periods: 2016-2035 (short term), 2046-2060 (medium term), 2081-2100 (long term); the 1986-2005 data were considered as a reference period. The raw climate model data were bias corrected using the quantile mapping method [1].

RESULTS

In the historical period 1976-2017, the SPI and SPEI indices behave in agreement detecting the same dry and wet periods. In general, however, the negative values of the SPEI index are lower than the SPI ones.

The Pearson correlation coefficients between groundwater levels and drought indices at the time scales of 3, 6, 9, 12, 18, 24 and 36 months are very similar for the two indices. These are different for each well and for each time scale; the higher coefficients are observed at the time scales of 9, 12 and 18 months. The wells that have at least one coefficient greater than 0.7, are 14. For brevity, in Figure *1* only the results for one well (PR55-01) and the SPEI at different time scales are shown. The points represent the observed groundwater levels, the solid line is the regression line and the dashed lines are the confidence intervals; in the box the values of the correlation coefficient are shown. For this well, the best correlation occurs at the time scale of 18 months.

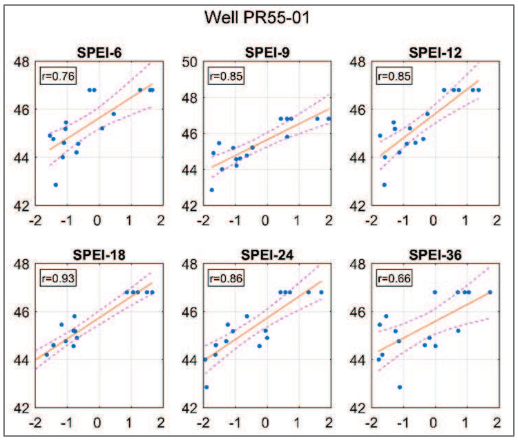

Figure 1 – Linear regression model for a well in the Enza basin with SPEI at the time scale of 3, 6, 9, 12, 18, 24 and 36 months. The x-axis shows the SPEI values and the y-axis the groundwater level in m a.s.l..

For each well, the future analyses were carried out only for the time scale with the higher correlation coefficient.

Groundwater level projections are different for the two drought indices. The analysis with the SPI does not detect significant changes in the three future periods; instead, the evaluation with the SPEI predicts a decrease in groundwater levels, especially at medium and long term and for the RCP 8.5 scenario. In Figure 2 the cumulative distribution function of the groundwater level in May (PR55-01 well) as a function of the SPI-18 and SPEI-18 for RCP 8.5 are shown. In the figures, all the results of the 13 models have been considered as a single realization with equal reliability. In Figure *2*-b an increase of the frequency of the lower groundwater levels is observed. For example, let's consider the 10th percentile groundwater level in the reference period (44.8 m a.s.l.); it presents a frequency increase of 3% at short term, 14% at medium term and 21% at long term.

CONCLUSION

In the present study we assessed the ability of the two multiscale drought indices, SPI and SPEI, to predict the groundwater level fluctuations. In the historical period, the SPI and SPEI behavior is similar and both indices show high correlations with observed levels.

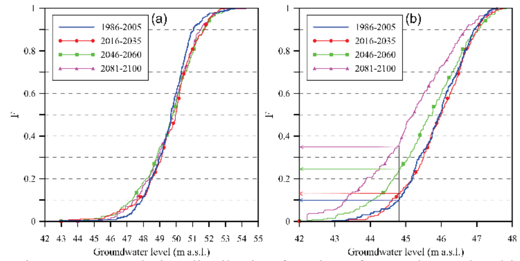

Figure 2 - Cumulative distribution function of groundwater level in May characterized by SPI-18 (a) and SPEI-18 (b).

Analyzing the future climate projections, we found that the analysis with the SPI predicts a not critical alteration of the groundwater levels. Applying the linear regression relationships with SPEI, an increase of the frequency of the low groundwater levels is noticed. In this study area, in fact, the future projections show a very small decrease of the precipitation and a remarkable temperature increase: and index that only consider precipitation cannot be able to detect the effect of climate change on the groundwater levels. On the other hand, the SPEI is able to quantify the effect of the precipitation-temperature changes projected by the RCM models.

ACKNOWLEDGMENTS

We thank dr. M. Marcaccio (ARPAE, Bologna, Italy) for the help during the data collection and L.G. Comito for the contributes in research during her master thesis.

REFERENCES

[1] D'Oria, M., Ferraresi, M. and Tanda, M.G., 2017. Historical trends and high-resolution future climate projections in northern Tuscany (Italy). Journal of Hydrology, 555, 708–723.

[2] Jacob, D., Petersen, J., Eggert, B., Alias, A., Christensen, O.B., Bouwer, L.M., Braun, A., Colette, A., Déqué, M., Georgievski, G., Georgopoulou, E., Gobiet, A., Menut, L., Nikulin, G., Haensler, A., Hempelmann, N., Jones, C., Keuler, K., Kovats, S., Kröner, N., Kotlarski, S., Kriegsmann, A., Martin, E., van Meijgaard, E., Moseley, C., Pfeifer, S., Preuschmann, S., Radermacher, C., Radtke, K., Rechid, D., Rounsevell, M., Samuelsson, P., Somot, S., Soussana, J.-F., Teichmann, C., Valentini, R., Vautard, R., Weber, B. and Yiou, P., 2014. EURO-CORDEX: new high-resolution climate change projections for European impact research. Reg. Environ. Change 14, 563–578.

[3] Mc Kee, T.B., Doeskin, N.J., Kleist, J., 1993. The relationship of drought frequency and duration to time scales. In Proceedings of the 8th Conference on Applied Climatology, Anaheim, CA, USA, 17–22 January 1993, 179–184.

[4] Vicente-Serrano, S. M., Begueria, S. and López-Moreno, J. I., 2010. A multiscalar drought index sensitive to global warming: the Standardized Precipitation Evapotranspiration Index, J. Climate, 23, 1696–1718.