LINEAR TIME SERIES MODELLING FOR GROUNDWATER LEVEL FORECASTING: THE CASE STUDY OF THE FRACTURED AQUIFER SYSTEM OF MONSUMMANO TERME (CENTRAL ITALY)

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Accurate forecasting of groundwater level is a useful tool to support sustainable water management. This study addresses the problem of forecasting groundwater hydraulic heads using linear models. The studied system is the carbonate aquifer located at Monsummano Terme in Tuscany Region, central Italy. It has been identified as an independent thermal groundwater system, with a fractured structure, physically separated from the nearby aquifers; no interactions with the neighboring Lima river have been found. The average altitude of the recharge area has been identified in previous studies between approximately 150 and 300 m a.s.l., coinciding with local carbonate outcrops. The system's conceptual model and preliminary analysis of groundwater level and meteorological data suggest the presence of a linear relationship between precipitation (considered as the system input) and hydraulic heads in response to them (system output). This relationship has been investigated by implementing linear models such as Auto Regressive models (AR) and Auto Regressive models with exogenous inputs (ARx) on the following data series, available for the 2005-2015 period: (1) daily values of cumulative precipitation registered in a nearby meteorological station and (2) groundwater hydraulic heads measured in a pilot well. These models consist in linear combination of groundwater heads and precipitation at previous time-steps whose output is the predicted groundwater heads at the successive time-steps; like other data-driven techniques, their implementation requires a complete series of historical meteorological and hydrogeological data, but no other hydrogeological features are directly involved in the models implementation. This study was developed in three phases: (1) exploratory analysis of the available data and identification of the conceptual model of the system, leading to the choice of linear models as the most appropriate solution; (2) implementation of the models on the training set and determination of their order by comparing the effectiveness of several models with different orders on both training and test sets; and (3) results and error analysis aimed at determining the worthiness of these kind of solutions. An in-depth examination of the errors has been carried out aiming at both quantifying the errors (determining accuracy of the models) and understanding whether they contain residual information. The latter could indicate the occurrence of phenomena in the system that are not represented by the model. The predictive power of the models has been tested on one day and three days ahead predictions. The ARx model outperformed the AR model, reaching a fitting of 95.22% in terms of Normalized Root Mean Square Error (NRMSE) on the training set and 94.4% on a test set on the one day ahead prediction. On the three days ahead prediction the fitting was 87.14% on the training set and 85.35% on a test set. Results showed that linear models are appropriate techniques for

forecasting groundwater hydraulic heads in systems characterized by a linear and time-invariant input-output relationship such as small systems, with no snow accumulation and a relatively reduced effect of evapotranspiration. The accuracy of the forecasting models obtained in this study allows for further investigations of the system: they can be useful and accessible tools to explore future rainfall scenarios and to examine the effects of new groundwater abstractions on existing wells.