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title: **Recent trends in groundwater levels in shallow hydrological system in the Czech Republic**

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A very complex geology of the Czech Republic led to defining many hydrogeological zones. The area of the country is currently divided into 152 zones in three layers — 111 zones in the main layer, 38 in the top layer (comprising zones in the Quartenary sediment) and 3 zones in the layer of basal Cretaceous aquifer (Olmer et al., 2006). Groundwater patterns of the most of the zones in the main layer and of all zones in the top layer are evaluated regularly based on data from shallow boreholes, measuring first unconfined aquifer (with depth mainly to 15 m). The evaluation of groundwater levels for individual years is processed usually as a comparison to the monthly cumulative-frequency curve (1971–2000). However, it does not provide comprehensive information about the long-term system development necessary for water policy and groundwater resources assessment.

We assumed that the trend analysis provides important information about changes in groundwater levels in a hydrological zone. Regarding the nature of investigated data, it is difficult to test the groundwater levels directly with simple methods such as linear regression. The seasonality of shallow groundwater systems with a typical cycle of spring maximum and autumn minimum and serial dependences in the time series complicates the resolution of trends in groundwater levels. A representative subset of 380 wells (from the total amount of 992 wells currently under observation) was tested. The selection was based on the amount and quality of available data; only time series with less than 5% missing data in the period of 1971–2009 were processed. We tested monthly medians in order to minimize the influence of outliers caused by measurement errors. Using the linear interpolation method gaps were filled. We used a seasonal decomposition of the time series to seasonal and residual components and tested the trend in residuals of monthly medians. Time series were separated into components of seasonal fluctuation and residuals based on the formula (1).

$$y = \alpha + \beta \sin(2\pi t) + \gamma \cos(2\pi t) + \varepsilon \qquad (1)$$

where t represents time, scaled so that the complete annual cycle is of length 1.0, α, β, γ are parameters of the model and ε is the residuum (Crawley, 2002). We also tested the significance of the model parameters (1) before we evaluated trends in residuals.

Standard F-test was used to test the significance of upward or downward trends in residuals ($p < 0.05$).

The results showed that 36% of shallow boreholes have been significantly decreasing, while the long-term increase of groundwater level occurred by 25% of tested wells. Regarding the spatial distribution of objects revealing significant change, we cannot draw any general conclusions describing the situation in the Czech Republic (Figure 1). However, the results from monitoring objects provided important information for further, more detailed evaluation of individual hydrogeological zones. The information about trends is valuable especially for zones of top layer (Quaternary sediments) and zones covering Proterozoic and Palaeozoic Crystalline rocks where the shallow boreholes provide together with spring yield the only information about the groundwater condition (Figure 2).

In conclusion the applied decomposition method provides a simple tool that allows operating larger datasets, however it is worth noting that the function (formula 1) for separation of seasonality may not always capture completely the nature of groundwater cycle.

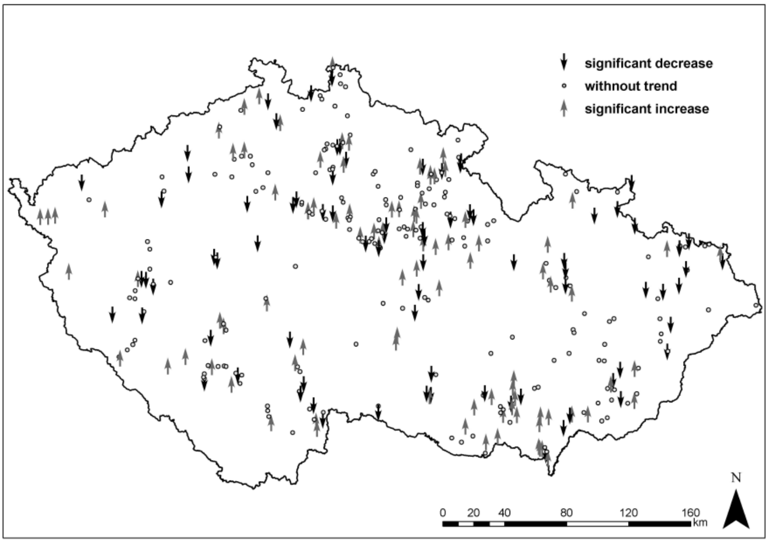

Figure 1. Trends in groundwater levels in the Czech Republic between 1971 and 2009.

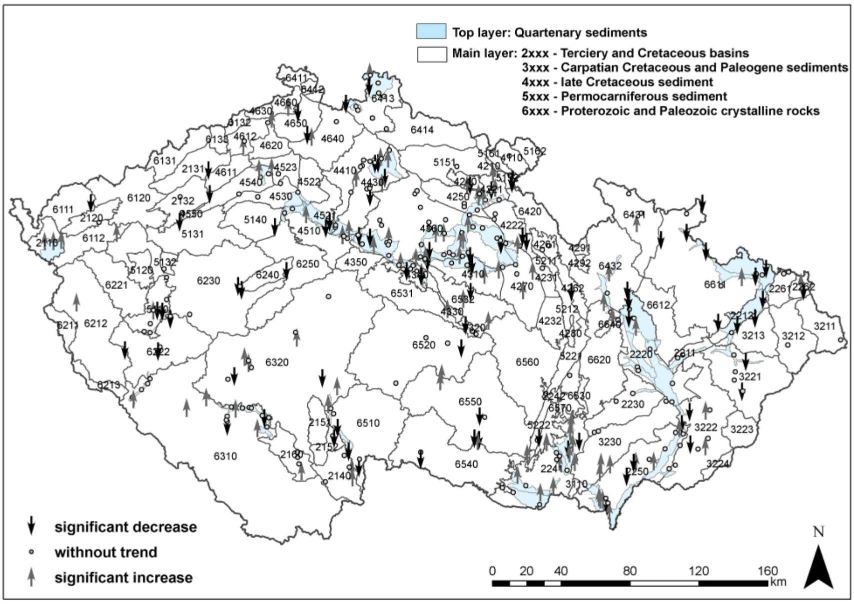

Figure 2. Trends in groundwater levels in the Czech Republic between 1971 and 2009 in hydrological zones.

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