Hydrological risk assessment in an abandoned coalfield: ten years of monitoring in Liège (Belgium)

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Context of the hydrological survey in the coalfield of Liège : outbreak in 2002 in Cheratte

Objectives:

- Determine if groundwater rebound is still active
- Understand spatial and temporal variability of groundwater fluxes
  - Identify response time of groundwater to rain events
  - Obtain indications on storage capacity of the aquifer.

Use of time series analysis as a risk management tool to understand how groundwater pressure spreads in an abandoned coalfield

Based on techniques used in karstic hydrology

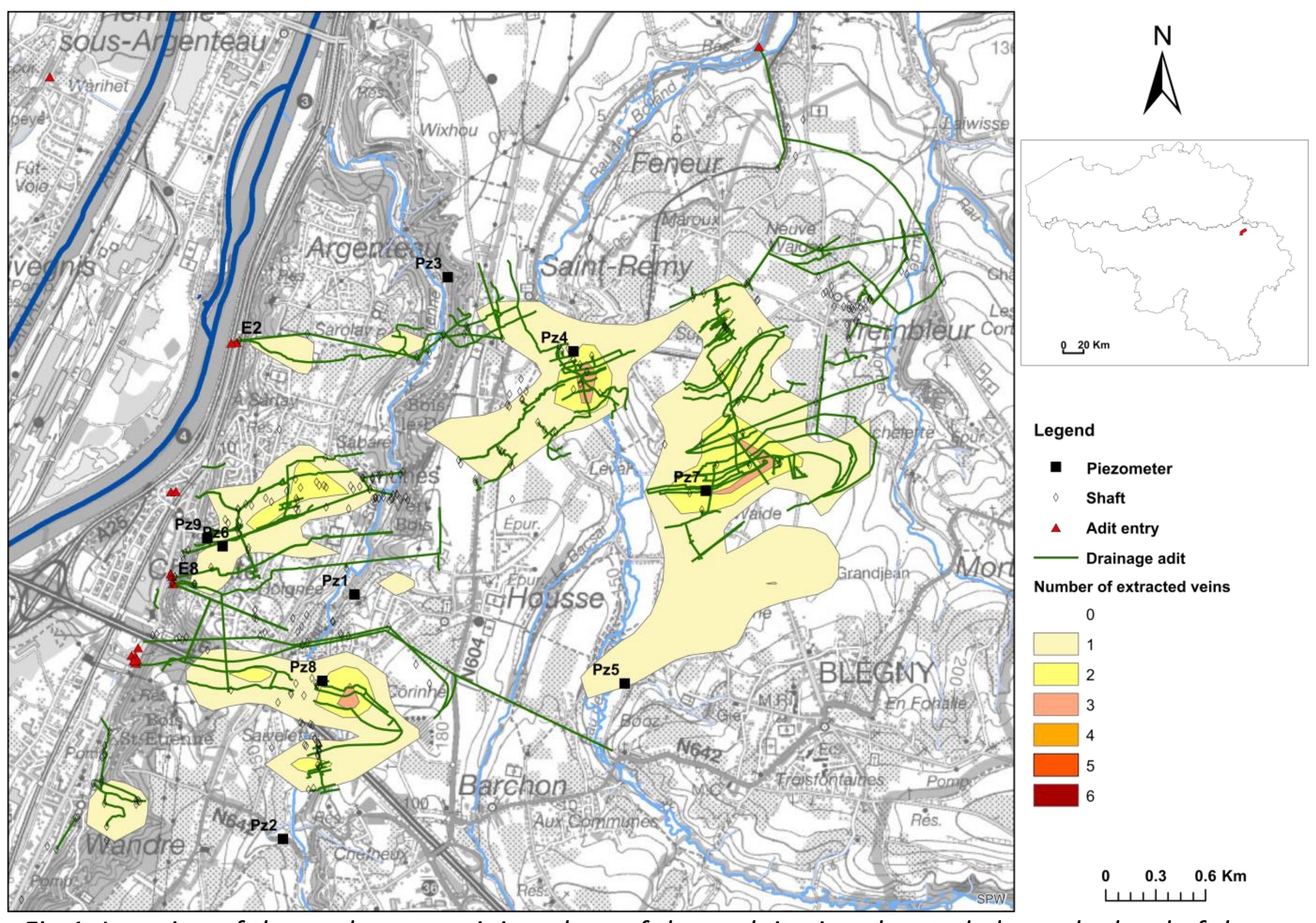

Fig 1: Location of the study area, mining plans of the exploitations located above the level of the Meuse River (55m) and measurement setting

1. Hydrologic time series

Groundwater and discharge peaks are generally observed in January and minima in November. The amplitudes of groundwater level variation differs largely from one location to another (Fig 2).

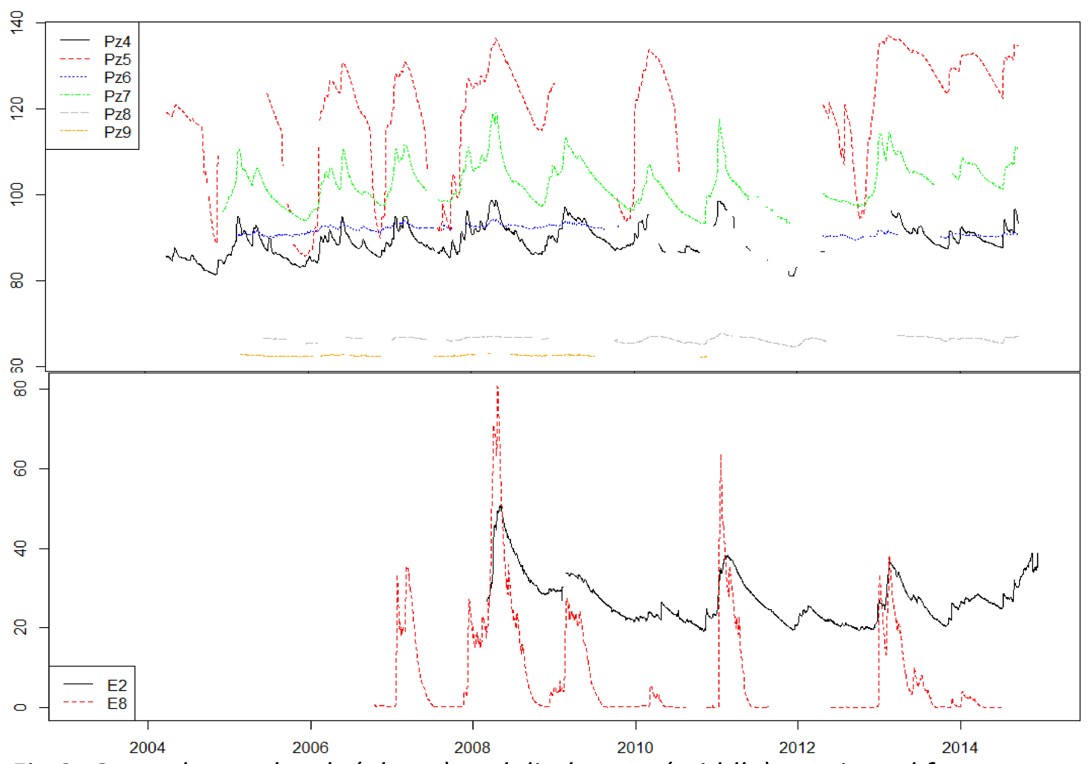

Fig 2: Groundwater levels (above) and discharges (middle) monitored from 2004 until 2014.

2. Decomposition of time series

Time series were decomposed in a sum of seasonal and general trends, calculated by moving averages, with a random variation. Small amplitudes of the seasonal and random variation indicate that quick responses of the aquifer to localized recharge events are limited. The ratios between the variances of the general/seasonal trends and the original data series give the relative importance of each component [1]. Piezometric levels measured in **Pz6** are clearly dominated by the **general trend** and almost not influenced by other components (Fig 3) .

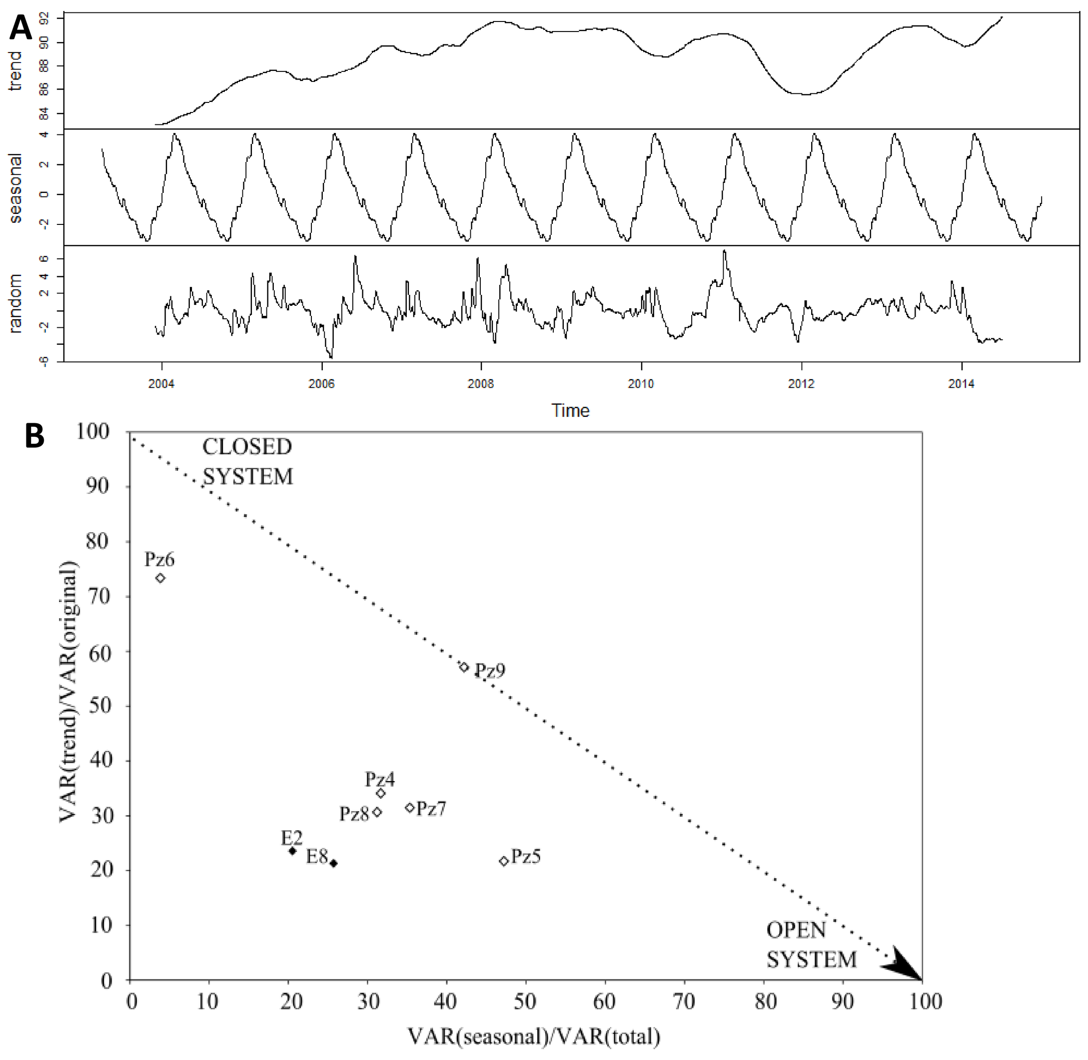

Fig 3: A - Time series decomposition for Pz4; B - Comparison of the trend variance ratios vs seasonality ratio (expressed as percentages)

3. Correlation

3.1. Auto-correlation function

The auto-correlation function of all time series gives an indication on the memory effect of the data series characterized by the decorrelation lag time (time to reach an auto-correlation value of 0.2) [2].

- A long decorrelation time indicates for instance a long memory effect which can be due to seasonal recharge [3], or to a poorly connected system with a major groundwater stock.
- A short decorrelation time indicates a short memory effect which would be typical for a system reactive to single events [4].

Location	Decorrelation time (days)
Pz4	5
Pz5	7
Pz6	4
Pz7	9
Pz8	9
Pz9	6
E8	4
E2	2

In general, **short decorrelation** times are observed in this study case. **Pz7 and Pz8** are probably located in areas with **larger storage capacities** than the other monitoring locations.

3.2. Cross-correlation function

With this analysis, responses to recharge events are studied to understand infiltration duration in the aquifer and the degree of connectivity between different locations. Cross-correlations are calculated between:

- the variations of data over the whole monitoring period (10 years),

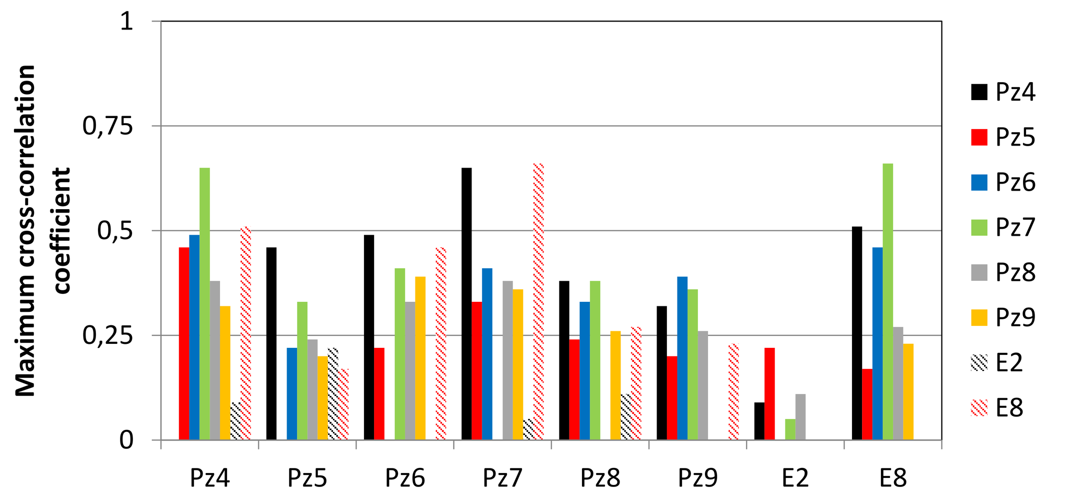

Fig 4: Maximum cross-correlation coefficients calculated between the groundwater levels and discharges, with time lags of 0 to 3 days, except for E2 (time lags 1-36 days).

- and at the scale of 25 selected single events in piezometers Pz4 and Pz7, discharge adits E2 and E8 (01/2008 -10/2014).

	PZ4 –PZ7	PZ4 –E2	PZ7–E2	PZ4–E8	PZ7–E8
Significative events	14	14	17	13	15
Non significative events	1	1	4	3	2
Average maximum cross-correlation coefficient	**0,77**	**0,61**	**0,63**	**0,71**	**0,69**
Average time lag (d)	2,14	1,21	2,94	-2,14	-0,41

Correlations at the different time scale show that **interconnections** can be **active during events** while they are **less** active **during baseflow** (i.e. E2)

4. Rain data

Rainfall time series are difficult to interpret based on the previous methods as they result into fuzzy trend components, non significant auto-correlation and cross-correlation functions.

4.1. Gain function (spectral analysis)

To assess the attenuation of the rain signal in the groundwater table, the gain function is calculated, according to spectral analysis methods [5]. The frequency at which the gain function equals :

- 1 (attenuation) is considered to indicate the duration to reach baseflow conditions after an impulse response.
- 0.4 is considered as indicating the quickflow duration through the system, if it is reached in a short period of time [4,5].

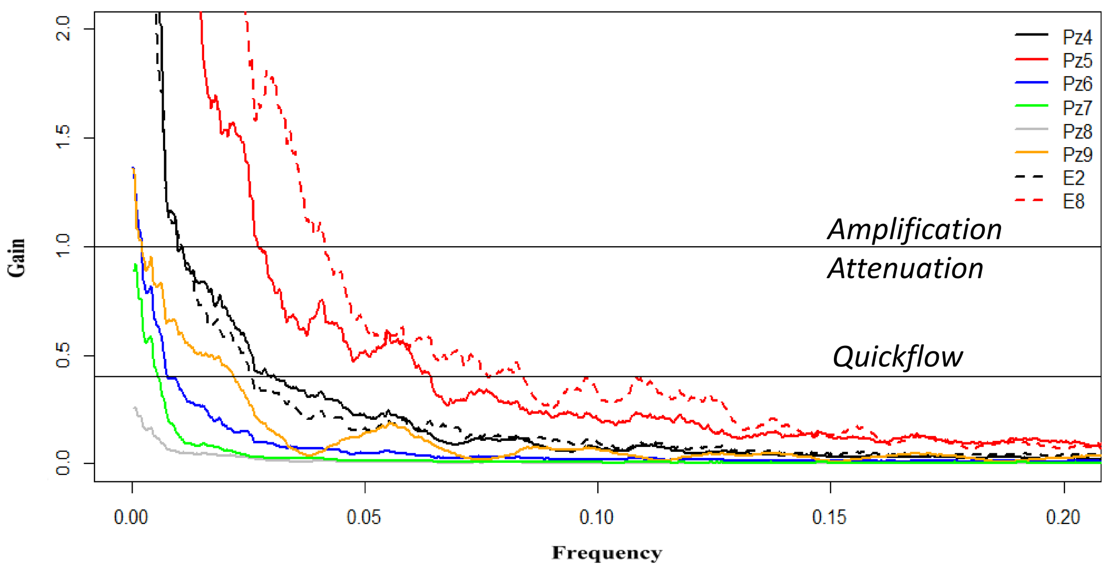

Fig 5: Gain functions calculated between the piezometers and the drainage adits, with time lags of 0 to 3 days, except for E2 where time lags of 36 days were calculated.

Quickflow is a **limited** process in this system (Fig 5) as short periods (<20 days) are only observed in Pz5 and E8.

Periods corresponding to the baseflow duration are also short in **E8** and **Pz5**, characterizing **small storage capacity** in contrast to periods of baseflow duration calculated for **Pz6 and Pz8**, indicating **larger storage capacities** in those locations .

4.2. Cross-correlation function

Cross-correlation functions are calculated for throughfall data averaged over 3 days. Throughfall data is derived from the rain data by the Thornthwaite equation, based on the hypothesis that the soil has a storage capacity of 125mm.

	PZ4	PZ7	E2	E8
Significative events	12	13	17	13
Non significative events	4	9	6	6
Average maximum cross-correlation coefficient	-0,22	-0,12	**0,41**	0,03
Average time lag (d)	2	-1	0	-2

The highest average maximum cross-correlation coefficients for peculiar rain events are reached when correlated to discharge adit **E2**, suggesting that for **some events**, **quickflow** should be considered in this drainage adit.

Conclusions:

The **time series analysis** is an **efficient low cost tool** to improve a monitoring network for mining risk management purposes.

It helps understanding the interconnections of different zones and the reactivity of the groundwater table at different locations in the mine.

No galleries connect Pz4, Pz7 and E8 (Fig 1) but hydraulic pressures are clearly transferred between those locations (§3.2).
Pz6 is located in an area with almost no connections (Fig 3; Fig 4)
E2 probably drains another area (Fig 4) but is connected to this study area during rain events (§3.2.). It also drains directly rain (§4.2.).
Storage capacity is larger around Pz6 (Fig 5), Pz7 (§3.1.) and Pz8 (§3.1.; Fig 5).

Considering different time scales (whole monitoring period vs event time scale in §3.2.) allows to give new insights on the active flux processes in the mine system (e.g. quickflow or not).

References

[1] Lafare 2015; [2] Larocque et al., 1998; [3] Sahu et al., 2009; [4] Panagopoulos and Lambrakis, 2006 [5] Padilla and Pulido-Bosch, 1995

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