Assessing post-mining risks in the long term: ten years of hydrological monitoring in Liège (Belgium)

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Abstract

One of the major environmental changes observed after mine closure are associated to groundwater flow and the coupled stress redistribution in the subsurface. Flooding of the mined voids starts as soon as the extensive pumping required during mining activities stops. This process called "ground water rebound" continues until mine water levels equilibrate with the regional ground water surface or reach a point of discharge. In case no such point of discharge exists (e.g. due to the collapse of drainage adits) outbreak, flooding and/or stability problems can occur in the surrounding area (Wolkersdorfer 2008).

Management of risks associated to former mining activities is thus essential to ensure public safety where extraction activities have been intense for several centuries, e.g. in Wallonia (Pacyna and Salmon 2012). To assess these risks, flow rates at discharge adits and groundwater levels have been monitored for 10 years in an abandoned coalfield in the area of Liège (Eastern Belgium). A statistical study is conducted on the long term data, aiming at understanding groundwater behavior and improving the monitoring network. Annual trends calculated from time series decomposition are used to evaluate if groundwater rebound is still active or not in the study area. Spatial and temporal correlation analyses between piezometric levels and discharge rates allow identifying response time of groundwater to recharge events and to obtain indications on the storage capacity of the aquifer.

This study shows how statistical analysis of a long term database can be used as an efficient low cost tool to improve a monitoring network for mining risk management purposes since it helps understanding connectivity and reactivity of the groundwater table at different locations in the mine.

Key words: Abandoned mines, mining risk management, temporal analysis

Introduction

On February 27th 2002, an outbreak occurred North of the city of Liège (Eastern Belgium), in the Meuse valley where intense coal extraction activities took place during several centuries (Pacyna and Salmon 2012). Last pumping phases stopped in 1982 in this abandoned coalfield. The event of 2001 triggered the set-up of a monitoring system to assess risks of new outbreaks, floodings and/or stability problems in the surrounding area. Flow rates in drainage adits and groundwater levels in residual mine voids have therefore been measured for 10 years in this area.

Due to the presence of cavities and rubble zones, hydraulics within mine workings and within karst systems are considered to behave similarly (Burbey et al. 2000). Therefore, the use of time series analysis seems to be a valuable low-cost method to characterize flow processes in underground mines (Sahu et al. 2009), as it is a widespread method for characterizing karstic systems (Mayaud et al. 2014; Panagopoulos and Lambrakis 2006). Two main questions are addressed in this study: is the level of risk stable, and what is the response time in case of pressure anomaly? The level of risk is linked to groundwater rebound and increases if rebound is still active. Response times are linked to the storage capacity of the hydrogeological system, as it influences how fast groundwater pressure pulses propagate through the abandoned coalfield. Indeed, high transmissivity is observed as recharge events are drained on short period of time by quickflow processes (e.g. Padilla and Pulido-Bosch 1995) in systems characterized by low storage capacity. In contrast, baseflow is the dominant process controlling water release in systems with high storage capacity (e.g. Larocque et al. 1998).

Methods

Collected data was measured in a groundwater network of six piezometers (Pz4-Pz10 in Figure 1) monitored since 2003, with screens installed in mined out areas of the Carboniferous shales. Groundwater depths were either manually measured on a monthly basis or monitored with pressure sensors at an hourly resolution. Stream levels behind weirs with rectangular notch installed in two channels located in the valley were monitored with pressure sensors and used to calculate discharges at an hourly resolution. Daily means of piezometric data and of discharge values are used in this study.

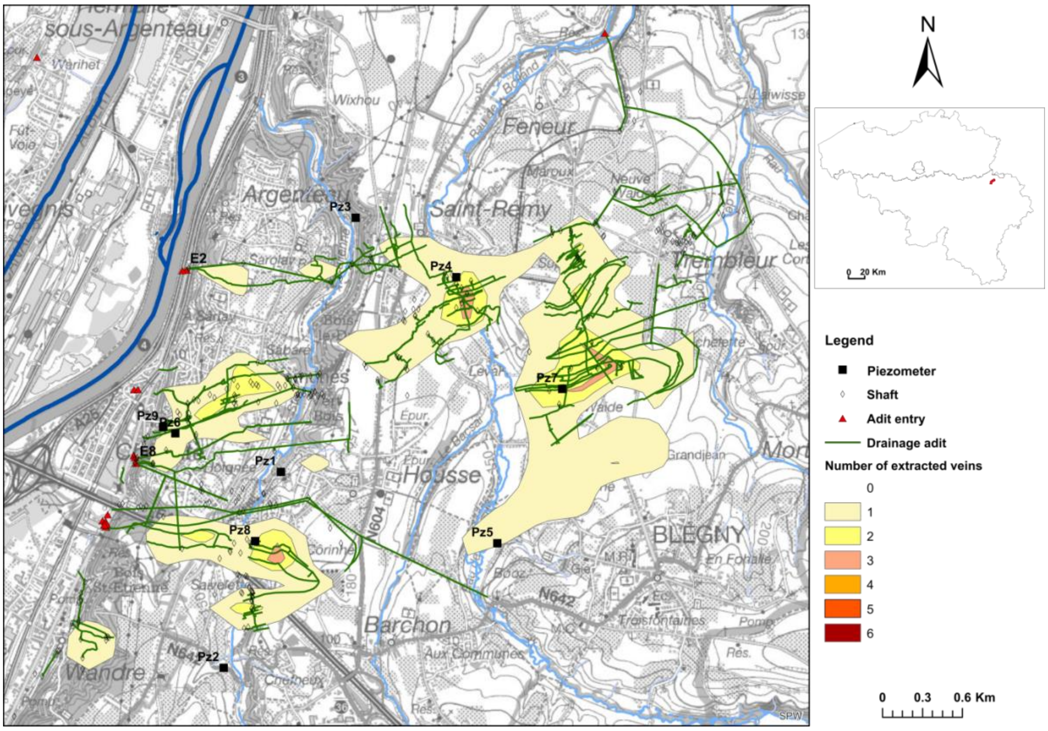

Figure 1: *Location of the study area, mining plans of the exploitations located above the level of the Meuse River (55m) and measurement setting*

Trend decomposition of water levels and discharge hydrographs, based on moving average calculations, allows extracting annual trends. These trends are used to evaluate if groundwater rebound is still active or not.

Correlation analyses are performed on the first derivatives of the time series, since stationary data are required. Consequently, conclusions of our study concerning spatial and temporal correlations refer to the *velocity* of groundwater level and discharge variation. Auto-correlation functions are calculated for each time series to identify memory processes in the data, considering that slow decreasing trends of auto-correlation function are attributed to slow mechanisms (e.g. seasonal recharge) and fast decreasing trends are induced by faster short term processes (e.g. reaction to single short recharge events). Finally, cross-correlation functions are evaluated to understand connections through the mined system at different time scales (long term vs. rain event) (Mayaud et al. 2014).

Results

Annual trends (Figure 2) calculated over ten years do not show any increase, suggesting that the groundwater rebound stopped before monitoring started.

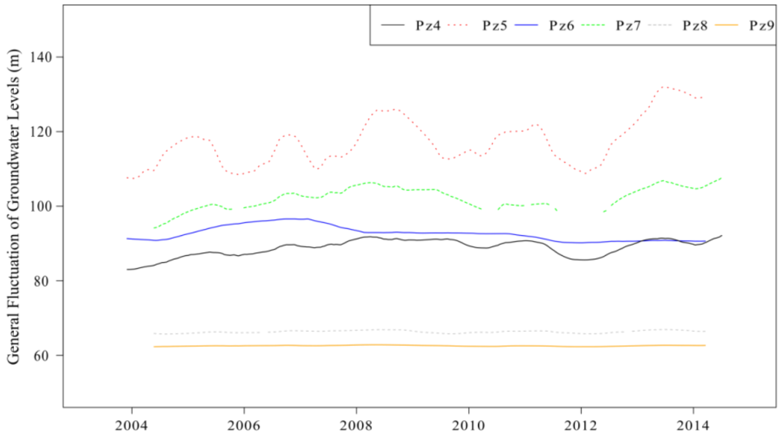

Figure 2 *General trends extracted from piezometric levels.*

Auto-correlation analyses allow differentiating locations in the mine influenced by slow and fast recharge processes, characterized by long and short decorrelation time, respectively. In general, short decorrelation times are observed in this study case. However slightly higher decorrelation times are calculated for Pz7 and Pz8, indicating these piezometers are probably located in areas with larger storage capacities than the other monitoring locations (d in Table 1).

The cross-correlation functions (ccf) indicate that some locations (Pz4, Pz7 and E8 – Table 1) in the mines are always connected to each other while no galleries connecting Pz4, Pz7 and E8 are reported (Figure 1), indicating that hydraulic pressure probably transfers through fractures or unknown rubble zones. In contrast, other locations are poorly connected to each other (low ccf for Pz6, Pz8, E2 in Table 1). Even if galleries seem to connect E2 with Pz4 and Pz9 with E8 (Figure 1), hydraulic pressures do not seem to transfer between these measurement points (low ccf in Table 1). However locations Pz4 and E2 are connected during rain events as maximum cross-correlation coefficients calculated for 14 selected rain events reached an average value of 0.61 within 2 days.

Table 1 *Maximum cross-correlations coefficients (ccf) between time series measured from 2003 until 2014 and decorrelation times (d in days) calculated by auto-correlation. All italic figures are related to coefficients >0.5 The underlined symbol « ns » stands for not significant values.*

	ccf							d
	Pz5	Pz6	Pz7	Pz8	Pz9	E2	E8	
Pz4	0.46	0.49	*0.65*	0.38	0.32	0.09	*0.51*	5
Pz5		0.22	0.33	0.24	0.2	0.22	0.17	7
Pz6			0.41	0.33	0.39	ns	0.46	4
Pz7				0.38	0.36	0.05	*0.66*	9
Pz8					0.26	0.11	0.27	9
Pz9						ns	0.23	6
E2							ns	2
E8								4

Conclusions

This study proved time series analysis is an efficient low cost tool to improve the understanding of groundwater fluxes through an abandoned coalfield. It helps understanding the interconnections between different zones and the reactivity of the groundwater table at different locations in the mine. The results show that outbreak risks due to groundwater rebound processes can be excluded in this area but that reported galleries from the exploitation maps (Figure 1) are not sufficient to understand the hydraulic connections between the different exploited zones. The statistical approach highlighted connections between measuring points that were not connected by galleries (Pz4-Pz7-E8) and showed that ancient galleries not always transferred hydraulic pressures (i.e. E2 - Pz4 and Pz9 - E8).

This study reveals that discharges in E8 evolve similarly to piezometric levels in Pz4 and Pz7, as cross-correlation analysis clearly proved hydraulic pressure must be transferred between these measurement locations. If data evolution differs between these points during future monitoring, investigations should be performed to know how pressure cannot be transferred by the usual way. In that case, further investigations should identify if pressure builds up somewhere in the coalfield or if it is transferred by another pathway. Hydraulic pressure can in that case be released by another pathway, as E2 drains this area at least during rain events. This observation proves that considering different time scales (whole monitoring period vs. event time scale) allows giving new insights on the active flux processes in the mine system (e.g. quickflow or not).

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