Journal of Hydrology 524 (2015) 326–332

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Preliminary results on the dynamics of particles and their size distribution at a karst spring during a snowmelt event

Ferry Schiperski [a,*], Johannes Zirlewagen [a], Olav Hillebrand [b], Tobias Licha [b], Traugott Scheytt [a]

[a] Technische Universität Berlin, Dept. of Applied Geosciences, Hydrogeology Research Group, Ernst-Reuter-Platz 1, 10587 Berlin, Germany

[b] Geoscience Centre of the University of Göttingen, Dept. Applied Geology, Goldschmidtstr. 3, 37077 Göttingen, Germany

ARTICLE INFO

Article history:
Received 22 August 2014
Received in revised form 12 January 2015
Accepted 20 February 2015
Available online 5 March 2015
This manuscript was handled by Laurent Charlet, Editor-n-Chief, with the assistance of Nico Goldscheider, Associate Editor

Keywords:
Turbidity
Suspended matter
Contaminant
Pareto distribution
Allochthonous
Autochthonous

SUMMARY

Recharge events in karst catchments are often accompanied by rapid changes of electrical conductivity, temperature or turbidity in associated karst springs. Turbidity is usually used as a proxy for suspended matter. However, it is not capable to characterize suspended matter in detail as it lumps signals of particles of a wide range of sizes. Changes in particle size distribution (PSD) of suspended matter have rarely been measured although they may contain information on particles' origin, transport, or mobilization. In few cases PSD could even be used to predict bacterial contamination of karst springs. This study is one among few, measuring concentrations of suspended particles in the size range of 0.5–150 μm on-site and in real-time. The study was performed during a single snow-melt event at one individual karst spring (Gallusquelle, Germany), the findings are therefore of preliminary character. Generally, the PSDs follow a power law (Pareto distribution). In some cases, however, a two parted Pareto distribution provides a better fit. The combination of chemograph analysis and turbidigraph separation demonstrates remobilized (autochthonous) and freshly infiltrated suspended (allochthonous) matter. Visually, there is no relation between PSD and the origin of the suspended matter. This may be caused by the superposition of signals from both origins. Therefore, utilizing the PSD as an indicator for the origin of suspended matter may be restricted to local applications. Furthermore, PSD does not seem to be a clear indicator for a bacterial contamination at the investigated spring, at least for this particular event. The study indicates, that the karst system itself and the type of discharge event may play a crucial role in the successful application of PSD as an adequate source indicator for suspended matter.

1. Introduction

Interest in the investigations of karst springs arises from their intensive use for drinking water supply (Ford and Williams, 2007). Fast infiltration and rapid transport of water are characteristics of karst aquifers, which contribute to their high vulnerability to contamination (Vesper and White, 2004; Fournier et al., 2007; Geyer et al., 2007; Hillebrand et al., 2012). Furthermore, the hydrogeological behavior of karst aquifers is complex. Determining universal indicator parameters for a deterioration of water quality is therefore challenging. Approaches have been proposed to predict bacterial contamination by using indicators like dissolved organic carbon, turbidity, and particle size distribution (PSD) at different karst aquifers (Heinz et al., 2006; Pronk et al., 2006, 2007; Heinz et al., 2009). Especially the easy-to-measure parameter turbidity has widely been used to understand the behavior and vulnerability of karst aquifers (i.e. Massei et al., 2003; Fournier et al., 2007, 2008). Some authors have even revealed a particulate-associated transport of bacteria in karst aquifers (Mahler et al., 2000; Dussart-Baptista et al., 2003). Still, different sources and nature of suspended matter may lead to a complex turbidity signal at the spring.

Transport of particles involves processes like direct transfer, deposition and resuspension (Fournier et al., 2007). Accordingly, Fournier et al. (2008) describe three potential origins of suspended matter in karst springs: (i) direct transport from the surface (allochthonous); (ii) resuspension of previously deposited sediments within the aquifer; (iii) erosion of autochthonous sediments within the aquifer. Pulse-through turbidity corresponds to (i), whereas flow-through turbidity corresponds to (ii) and (iii), respectively (Pronk et al., 2009). The ambiguity in turbidity signals restricts the use of turbidity as an indicator for the occurrence of contaminants (Massei et al., 2003; Pronk et al., 2006, 2007). Distinguishing the origin of turbidity may usually not be straightforward (Dussart-Baptista et al., 2003; Massei et al., 2003) but of

* Corresponding author. Tel.: +49 30 31472652.
E-mail address: schiperski@tu-berlin.de (F. Schiperski).

http://dx.doi.org/10.1016/j.jhydrol.2015.02.035
0022-1694/© 2015 Elsevier B.V. All rights reserved.

high significance as a way to predict deterioration of water quality. This has been shown by Pronk et al. (2006, 2009) who found that contamination by fecal bacteria is expected for an allochthonous turbidity rather than for an autochthonous. Due to the capacity of bacteria and contaminants to sorb on suspended particles, it is important to comprehend the dynamics of suspended sediments in karst aquifers (Fournier et al., 2008). The PSD of suspended matter allows for a further insight into the turbidity of spring water and contains more information compared to the lumped parameter turbidity. For example, Pronk et al. (2007) used the PSD as an indicator for microbial contamination in a karst spring. They found relatively smaller particles to be related to an allochthonous turbidity and to bacterial contamination, whereas relatively larger particles were detected during periods of autochthonous turbidity.

So far, only a few studies have measured PSDs at karst springs. Moreover, still less of them have been performed in situ and in real-time, even though this is crucial for data reliability (Wilkinson and Lead, 2007).

The aim of this study was to examine the event based changes in PSDs online and in real-time. It has been performed during a single snowmelt event in a individual karst spring in SW-Germany and is therefore of preliminary character. PSDs are correlated with commonly measured physico-chemical parameters in karst springs. Additionally, we propose a generally and easily applicable tool for a quantitative data interpretation of the PSDs.

2. Material and methods

2.1. Study site

The investigated karst spring Gallusquelle is located in Southwest Germany about 70 km south of Stuttgart (Fig. 1). The spring has a mean discharge of 0.5 m^3/s and is fed predominantly by autogenic recharge. The catchment has a size of about 45 km^2 and is of rural character – the urban area covers only 3% of the catchment. The aquifer consists of limestone of the Upper Jurassic and has its main drainage at the Gallusquelle spring (Sauter, 1992). The groundwater flow is believed to occur in a network of conduits/fractures and small scale solution channels (Sauter, 1992). Primary sources for contamination in the study area are a storm water tank (SWT), which frequently discharges into dry valleys (Heinz et al., 2006; and Heinz et al., 2009), a combined sewer system (Hillebrand et al., 2012), agricultural use and roadway runoff. The relevance of the last two sources has not been investigated yet for the local study area, but for karst aquifers in general (e.g. Mahler et al., 1998; Boyer and Pasquarell, 1999). Measurements were performed after a snowmelt event in December 2012. The initial snow cover was 30 cm, averaged from three measuring stations close to the catchment. The snowmelt was induced by increasing air temperatures and rain in two consecutive steps. Consequently, a dual spring response was also observed and is divided into part I (12/15/12–12/22/12) and part II (12/22/12–12/26/12). The study mainly focuses on part I, as the sampling was performed during this part only.

2.2. On-site analysis

The particle sizes and their corresponding concentrations were monitored in real-time using a single particle counter (CIS1, Galai, Israel) equipped with a flow through cell. The measuring method is based on the time of obscuration, resulting from particles that are in the optical path of a rotating laser beam and a photodiode, also know as time-of-transition method (Aharonson et al., 1986). Spring water was directly pumped trough the device. Alteration of particles during transport or storage can therefore be excluded. During part I, measurements were performed for 10 min in an interval of 1 h. The measuring range for particle diameters extended from 0.5–60 μm range with a resolution of 0.2 μm. For part II the interval was set to 3 h with 30 min of measuring and the range was set to 0.5–150 μm (maximum range) resulting in a resolution of 0.5 μm. In situ analysis revealed that particles >50 μm were extremely rare, making the equipment ideally suited for its usage at the spring. The standard deviation was reported to be in the range of ±10–17% for monodisperse media (Schäfer, 1998) and the lower limit of detection to be 1000 particles/ml (Hofmann, 1998). The turbidity was monitored with an ULTRATURB PLUS (DR. LANGE), having an accuracy of ±1% and a precision of ±0.5%. The device measures scattered light, produced by a 860 nm infrared light, at 90° (DIN EN ISO 7027) and has a range of measurement of 0.0001–1000 NTU. Temperature and electrical conductivity were measured with a MSM-9 (UIT GmbH, Dresden, Germany). Coefficients of variation for the MSM-9 were calculated at 0.04% and 0.1% for EC and temperature, respectively. The calculation is based on 164 data points at stable conditions. The discharge was quantified hourly at a gauge located about 50 m downstream of the spring.

2.3. Sampling

Grab samples of spring water were taken at an interval of 6 h during part I of the event. The water was filtered through cellulose acetate (CA) membrane filters (diameter = 25 mm; 0.45 μm average pore size) into PET-bottles for anion and cation analysis. The samples were preserved using HNO_3 for cations and TTE (Trichlorotrifluoroethane) for anions and stored in a cooling box.

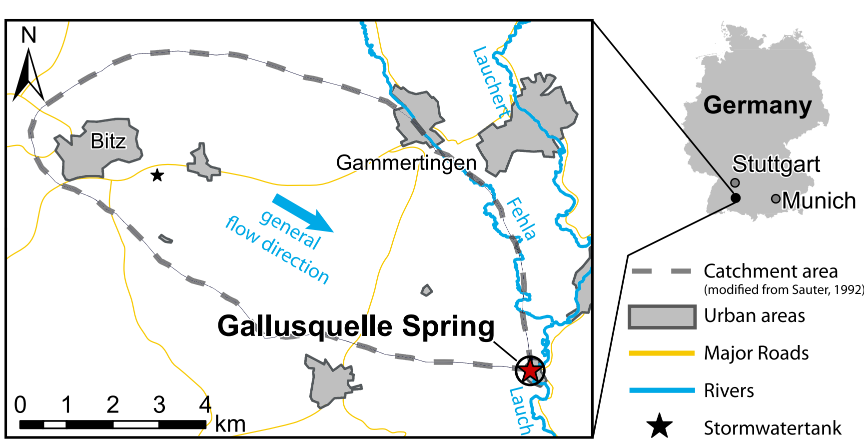

Fig. 1. The location of the Gallusquelle spring and its catchment. The groundwater flow is orientated in SE direction as indicated.