

Environmental health aspects of drinking water-borne outbreak due to karst flooding: case study

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ABSTRACT

Climate change may increase the incidence of waterborne diseases due to extreme rainfall events, and consequent microbiological contamination of the water source and supply. As a result of the complexity of the pathways from the surface to the consumer, it is difficult to detect an association between rainfall and human disease. The water supply of a Hungarian city, Miskolc (174,000 inhabitant), is mainly based on karstic water, a vulnerable underground water body. A large amount of precipitation fell on the catchment area of the karstic water source, causing an unusually strong karstic water flow and flooding, and subsequent microbiological contamination. The presence of several potential sources of contamination in the protective zone of the karstic water source should be emphasized. The water supplier was unprepared to treat the risk of waterborne outbreak caused by an extreme weather event. Public health intervention and hygienic measures were taken in line with epidemiological actions, focusing on the protection of consumers by providing safe drinking water. The contamination was identified, and measures were taken for risk reduction and prevention. This case study underlines the increasing importance of preparedness for extreme water events in order to protect the karstic water sources and to avoid waterborne outbreaks.

Key words | environmental health, karst water, monitoring system, vulnerability, waterborne outbreak, water quality

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INTRODUCTION

During recent decades there have been more and more events worldwide when water sources and supplies were threatened because of extreme weather conditions, particularly precipitation in large quantities and floods, which can contaminate surface and other water sources and supplies, thereby threatening waterborne disease outbreaks (Rose *et al.* 2001). There are only a few publications studying the association between heavy rainfall and human infectious disease, although the subject is an important concern in Europe (Kovats & Tirado 2006). After heavy rainfall, turbidity often increases in flooding watercourses, interpreted as an indicator of microbial contamination;

nevertheless hygienic examinations of watercourses are usually not carried out (Kistemann *et al.* 2002). Waterborne outbreaks of human infectious disease, for example cryptosporidiosis, have been linked to weather patterns such as heavy precipitation (Lake *et al.* 2005). The results of climate change, warmer temperatures and extreme rainfall are contributing factors to waterborne disease outbreaks (Thomas *et al.* 2006). Increased frequency of heavy rainfall events, with associated flooding and increased temperature also lead to deterioration of the quality of surface waters that could adversely affect human health (Hunter 2003). The karstic water sources are of particular concern in terms of

doi: 10.2166/wh.2010.099

extreme weather conditions because of their vulnerability (Rose *et al.* 2001). Investigation of the vulnerability of karstic water sources is important for the avoidance of waterborne outbreaks (Menne & Kristie 2006). Our observations in this case study highlight the sensitive points that should be checked during the operation of a karst-originated water supply system to avoid the widespread consequences of waterborne outbreaks.

METHODS

Characterization of water sources and drinking water quality

Hungary is relatively rich in groundwater. Therefore the extraction of drinking water is based mainly on bank filtration (39.4%) and protected deep wells (40.1%), as well as karstic (11.2%) water. Among these sources karstic water has a particular importance. Karst offers excellent quality of drinking water at low cost throughout most of the year. The city of Miskolc is situated in the northern part of Hungary. The city's water supply comes predominantly from the karstic aquifers of the Bükk Mountains.

Karst is a highly vulnerable aquifer because the formations covering the water-bearing layers do not offer

sufficient natural protection against surface contaminants (Bartram & Ballance 1996). The karst landscape in the Bükk Mountain, Hungary, is characterized by a thin layer of soil on the bedrock, through which precipitation can pass immediately and completely. The vulnerability partly stems from the geological structure itself, since karst is a good water conduit and has good reservoir properties. The other component is people living and working in the area of the water source resulting in environmental stress.

Non-compliance of samples taken from the Miskolc water mains have been extremely rare over a period of several decades. Bacteriological and chemical tests, carried out by the public health authority and by the waterworks, generally showed good water quality with a small number of exceptions (Figure 1). Currently, there are eight water-extraction facilities attached to the aquifers. Karstic water is extracted partly by gravitation from springs and partly from wells by means of pumping. The protective zone over the springs has an area of 291 km², of which the surface profile of the primary protective area is 171 km², while the secondary confined protective zone is 120 km².

The karstic springs are recharged from the Bükk Mountains. Most of the region is part of the Bükk National Park, which offers a degree of protection. However the existing settlements and holiday resort areas existing in the

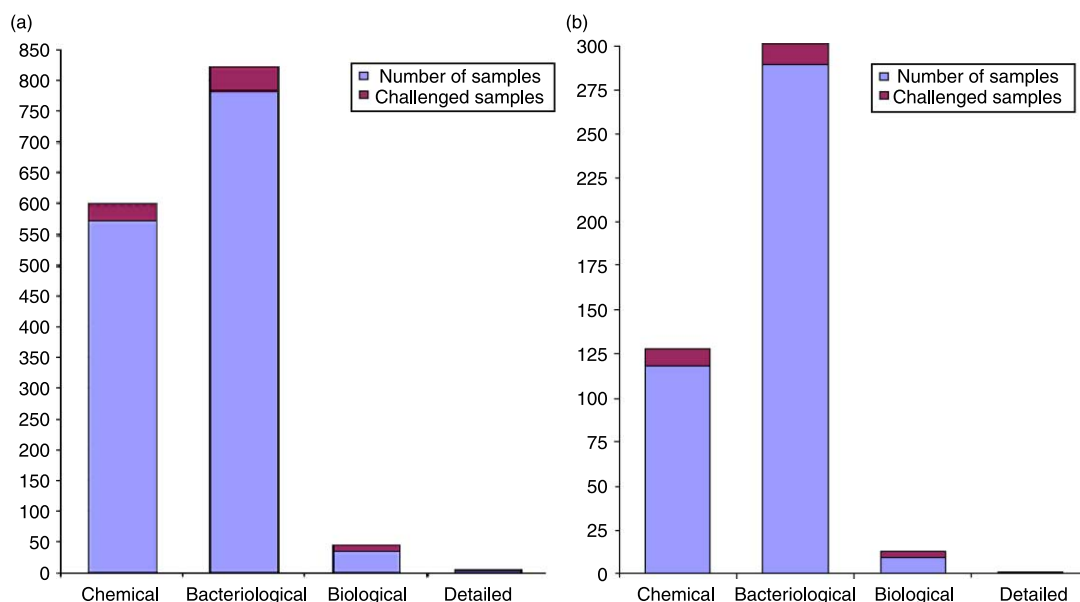


Figure 1 | Miskolc, 2006, samples taken and non-compliant samples from waterworks' own sampling (a) and public health authority sampling (b).

region display potential sources of contamination. Given the nature of land use, microbiological and nitrate contamination is the most likely. The Bükk Mountain settlements sit on the top of the underground streaming flows. As a result, for instance, contaminated water may reach the waterworks reservoir at Miskolc-Tapolca in 10–13 days. Water seeping into the karst can travel exceedingly long distances in 20 days (internal protective zone) or in 180 days (external protective zone). Although the settlements located atop the protective area are connected to sewerage systems—the proportion of homes connected in the different settlements varies—this, paradoxically, is an additional opportunity to contaminate the aquifer. Since mountain settlements do not have any built precipitation water conduit system, there are many illegal links to the sewage network. If precipitation is heavy, the system becomes overloaded and is seriously threatened with contamination. A specificity of a karst system is that, during heavy rainfall, flood waters race through caves and ducts at a tremendous speed, carrying huge amounts of sedimentation and picking up the sludge consolidated along the duct surfaces. This appears as turbidity of the water at the waterworks. It is possible to keep turbid water out of the water supply system by building sedimentation tanks, but this option was not available in 2006.

The drinking water consumption of Miskolc, which has approximately 174,000 residents, is 35,000–42,000 m³/d. The municipal water supply network consists of four basic zones that are more or less distinct according to the aquifer, and of two sub-zones. The basic zone 1 (which includes Miskolc-Tapolca, University Town and the southern part of the downtown area) waterworks wells are the city's most significant sources of drinking water, providing over 50% of the city's water demand. The first well, sunk in 1913, is 18 m deep including the water duct. In 1989 a 21 m deep well (the 'new well') was sunk into the same cave. Under it are caverns partly filled with scree. Both wells are linked by a natural duct.

Description of the events leading to the outbreak

The catchment area of the Miskolc-Tapolca springs is 76 km². Between 23 May and 6 June 2006, 215.8 mm/16.8 million m³ of precipitation fell on this area. The extreme

precipitation intensity resulted in 2.5–3 million m³ of surface water potentially capable of transporting any kind of contamination. Experts believe that the karstic water level began to rise on 24 May 2006, reaching a maximum level on 10 June, which is assumed to be the highest level ever recorded during this period of June 2006. The last uncontaminated sample taken from the wells was on 24 May and the first contaminated sample was taken on 6 June. The contamination must have entered the waters of the new well during this 13-day period, probably from multiple sources, given the waters and contaminants arriving over different periods of time. A decisive role in the bacterial contamination of the new well was played by the weather and the subsurface flooding it triggered, as well as by the numerous potential sources of contamination to be found on the protective zone. A committee investigating the event recorded a number of potential sources of contamination (illegal communal waste dumps, garbage, manure piles, outhouses with pit latrines that have to be emptied separately, liquefied manure treatment facilities), as well as sinkholes (creek water, lake water), limestone gulch (canyon) and treated wastewater.

The first reports of visible water turbidity in the mains caused by the rainfall—called in by residents—were received by the National Public Health and Medical Officers' Service (ÁNTSZ) on 3 June, but the calls came from the western part of the city and the springs affected were closed off from the mains. Samples indicated satisfactory water quality. In the affected section of Miskolc-Tapolca, there were no complaints registered and the waterworks did not report any problems with its Miskolc-Tapolca springs. The first report was on Thursday, 8 June, noting that a sample of the water taken by the waterworks on 6 June (the first working day following the Whitsun holiday) indicated contamination following a preliminary 48-hour test. The contaminated samples were not from the western part of the city but from the region supplied by the Miskolc-Tapolca waterworks. On the same day, from 1 pm on, the Epidemiological Department received a series of reports from general practitioners and paediatricians that larger numbers of patients had appeared with symptoms of diarrhoea. At this time it was unclear whether all of Miskolc would be affected by the outbreak. However, it was found

that patients were localized to the area supplied by the Miskolc-Tapolca waterworks. Public health and epidemiological investigations got under way as soon as the reports were received. They involved on-site investigations of the Miskolc-Tapolca waterworks and water samples were taken by the public health authorities.

During the investigations into the outbreak it was revealed that the level of turbidity at the Miskolc-Tapolca waterworks began to increase on Saturday 3 June at 12 noon, and when it reached its limit value at 2 p.m., water extraction from the well was halted. By 8 p.m., the turbidity dropped below the value of 10 NTU, so the well was reconnected to the mains. The water entering the mains with a turbidity value of 9–10 NTU was given a chlorine level of 0.4 mg/l. However, the turbidity value began to rise again; so on Sunday 4 June 2006 at 5.40 a.m., the well was disconnected from the Miskolc water supply. According to calculations, during the 9–10 h between the two stoppages of the well, 8,000–9,000 m³ of water entered the network. The water from the well was discharged into a brook for a long time because of lasting bacteriological in-compliance.

Water quality examination methods

The public health intervention was focused on frequent monitoring of water quality; identifying sources of contamination where possible and introducing preventive risk-control measures. The drinking water was examined immediately; bacterial indicators of faecal pollution (coliform bacteria, *Escherichia coli* and intestinal enterococci) according to the relevant EN-ISO methods as required by the relevant regulations were tested from 651 water samples. Unfortunately the samples were predominantly taken from the supply only after chlorination. Tests for thermotolerant *Campylobacter*, enteric viruses (immunochromographic preliminary test for adenovirus and rotavirus, IDEIA norovirus Elisa test, RT-PCR tests for both norovirus and hepatitis A) and protozoa (*Cryptosporidium* and *Giardia*) were carried out from a sample of 65 litres taken on 9 June at the wellhead from the compromised new well water. Regular water tests from this well were performed throughout the rest of the year.

RESULTS

Water quality tests findings

Bacterial examinations of water samples by both the operator and the authorities found clear evidence of faecal contamination (Table 1).

According to the results of tests conducted by the Water Hygiene division of the National Institute of Environmental Health (OKI), samples taken five days after shutting down the well still contained significant bacterial contamination. OKI found both *Cryptosporidium* and *Giardia* (not viable) and there were unconfirmed positive results for several viruses. The immunochromographic preliminary test was positive for adenovirus and negative for rotavirus, IDEIA norovirus Elisa test was positive, while RT-PCR tests for norovirus GI and GII genotypes and hepatitis A were negative. In the period 6–18 June, a total of eight non-complying samples were found (Figure 2).

The samples taken from the non-chlorinated well water showed faecal contamination over a longer period (Figures 3 and 4). The chemical test results were satisfactory.

Epidemiological and clinical laboratory findings

On 9 June 2006 physicians were alerted to report new incidents of acute gastrointestinal disease on a daily basis with the purpose of enhancing the surveillance system in operation, aiming at detecting cases linked to the waterborne outbreak. Case confirmation was based on experiencing acute gastroenteric symptoms or positive microbiological results confirming a gastroenteric infection with or without symptoms and living or working in the southern, exactly determined part of the city and having consumed drinking water from the contaminated supply between 3 and 8 June (primary case). During the outbreak 521 samples were transferred to the regional laboratory of the ÁNTSZ, and tested for common bacterial agents, and in 75 out of 521 samples *Campylobacter* species were isolated. By species-specific multiplex PCR testing *Campylobacter jejuni* was successfully identified from 14 samples and *Campylobacter coli* from four samples. Norovirus was identified in 29% of 69 faeces samples. Between 3 and

Table 1 | Non-complying water quality test results over the period of the emergency

Date sample taken	Sampling site	Sample taken by	Coliform/100 ml	HPC 22°C/ml	HPC 37°C/ml	<i>E. coli</i> /100 ml	Enterococcus/100 ml	<i>Pseudo-monas aeruginosa</i> /100 ml	Sulfite reducing anaerobic spore formers/100 ml
6–10 June 2006	Tapolca waterworks	MIVÍZ	200	3,000	-	200	-	-	-
	University (kitchen)	MIVÍZ	200	1,850	-	200	-	-	-
	Görömböly, Lavotta Street	MIVÍZ	80	290	-	80	-	-	-
	Görömböly, Lavotta Street	ÁNTSZ	70	100	15	70	30	0	0
	University (E/2 dormitory)	ÁNTSZ	15	160	14	15	2	0	0
	Tapolca well	OKI	920	-	-	810	83	-	32
	Tapolca parking lot	ÁNTSZ	200	80	80	200	60	0	0
	Görömböly, Lavotta Street	ÁNTSZ*	0	2	-	0	Salmonella NT/51	-	-

*Salmonella species (NT) was found in 5 litre sample.

MIVÍZ, Miskolc Waterworks; OKI, National Institute of Environmental Health.

22 June, 3,673 cases were linked to the outbreak, and 161 patients were admitted to hospital with the symptoms of gastroenteritis.

Outbreak confinement measures

The epidemiological actions were focused on organizing safe drinking water supply for the residents. Alternative drinking water was provided for the affected region (water supplied in bottles, plastic bags or trucks). Distribution of alternative drinking water was done using mobile facilities based on schools, or public institutions, and making use of the media to announce the distribution venues. Orders were issued to decontaminate all affected water mains, including thorough rinsing throughout the entire city; bacteriological and chemical tests were performed daily. The initial chlorine level in the zone was increased to 2g/m³ at the site where the water entered the system. Booster chlorination was conducted by means of mobile devices at the critical points to guarantee a level of at least 0.6–0.8 mg/l at the end-points. Free chlorine levels were continuously monitored. Divers steadily extracted the contaminated debris accumulated in the cave conduits. To promote the cleanup, the water from the wells switched off from the supply was led into the surrounding ditches. Marginal disinfection was provided for this water too, because a creek near to the affected area was used for illegal bathing. The missing drinking water—5,000 m³/d—was replaced from a nearby waterworks (ÉRV Rt.). At the transfer points, the operators were required to check daily for bacteriological and chemical contaminants and every third day for pollutants by microscopy. The public was briefed through the daily press and other media releases. This included general information on waterborne diseases and ways of avoiding contracting infection by person-to-person spread. In addition, the residents were regularly briefed on the actual water quality. A constant free active chlorine level was maintained in the mains, and repeated tests of drinking water quality allowed the provision of bottled water to cease at midnight on 13 June 2006. However, public health experts continued to recommend that residents should boil water for ten minutes before drinking it. Finally, after a further three days, on the basis of the laboratory test results, the consumption of water without restriction was allowed

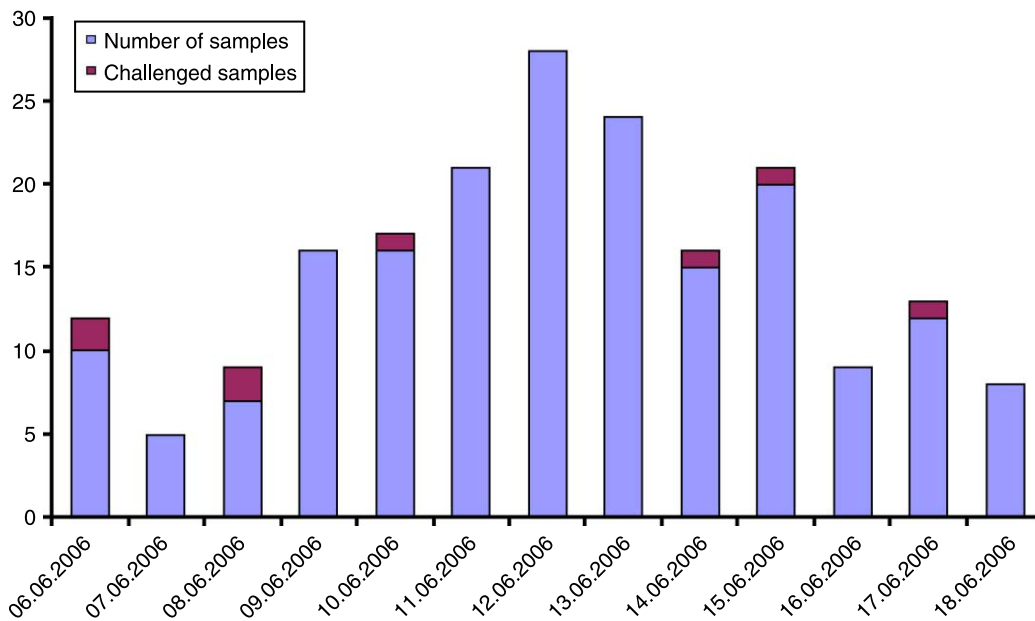


Figure 2 | Bacteriological samples in mains and number of non-compliant samples, 6–18 June 2006.

on 16 June 2006. After the disconnection of the affected (Miskolc-Tapolca) waterworks from the system on 4 June 2006, daily bacteriological tests of the untreated and chlorinated water, as well as of the water in the surrounding ditches were carried out. The exceptional bacterial contamination noticed in June had ended by the last days of August, and at the beginning of September the quality of the spring was found to be satisfactory. The quality of the drinking water in the system—following disinfection—complied with the quality minimum set forth in the government decree (201/2001 (X.25.) Korm.).

DISCUSSION

In Hungary regulations oblige the owners and operators of the public drinking water supply companies to assess the vulnerability of the water sources and to adopt measures for controlling the associated risks. MIVIZ, the Miskolc municipal drinking water supply company, despite a hydrogeologically well-established vulnerability assessment showing a multitude of potential contamination sources, failed to respond to these obligations. The owner (i.e. City of Miskolc) turned the incomes incurred from the water price

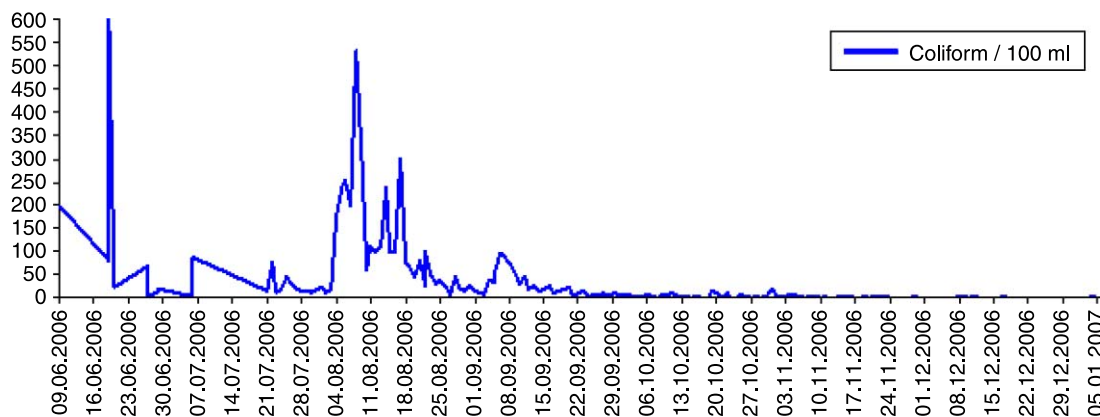


Figure 3 | Trend of coliform bacteria numbers in the untreated water of the Miskolc-Tapolca waterworks, 9 June 2006 to 5 January 2007.

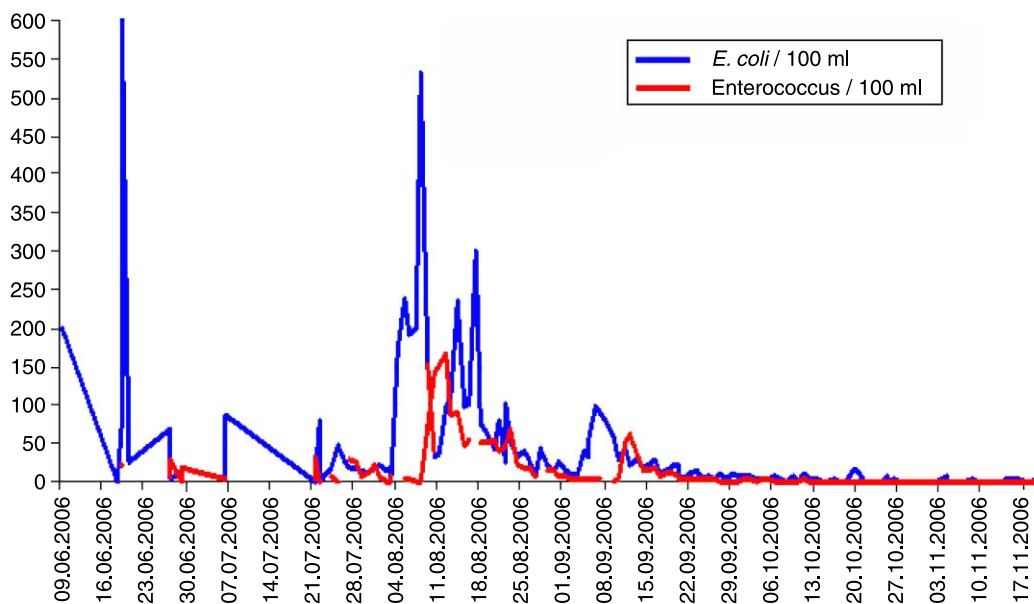


Figure 4 | *E. coli* and *Enterococcus* numbers in the untreated water of the Miskolc-Tapolca waterworks, June–November 2006.

to different purposes and neglected to address the risks even by establishing a competent monitoring system and appropriate treatment of the water before distribution. The waterworks supplying the second biggest city of Hungary did not even have a routine bacteriological laboratory.

In the course of the extreme weather events preceding the outbreak, even clear signs of the risk were ignored and the only measure taken for the safety of the supply was a marginal chlorination. A single tool of regular monitoring was a continuous turbidity measurement but only extremely high turbidity, far exceeding the legally binding parametric value, led to disconnection of the affected wells from the supply. There was no information and no investigation was made into the causes of the high turbidity, and after the turbidity dropped below the arbitrary limit value the well was reconnected to the mains, which shows the neglect by and unpreparedness of the water supplier for the consequences of an extreme water event and a lack of knowledge of the possible consequences of events leading to high turbidity. After a few days the turbidity value began to rise again and the well was eventually disconnected from the water supply system. There was again no investigation into the cause of high turbidity. A few days later the greatest waterborne disease outbreak of the last 50 years in Hungary gave a

lesson on where such neglect can lead. Should the water supplier have had access to a real-time water quality monitoring system the water contamination could have been discovered much earlier, and the outbreak could have been completely avoided or at least confined much earlier. Although the hydrogeological protective zone was identified in 1987, many of the measures and tasks defined by legal obligation were not implemented. If the aquifer protection programme introduced in 2002 had not been halted in 2004, there would have been a better chance of organizing and maintaining a safe water supply.

Lessons learnt

In order to meet public health requirements before re-starting the waterworks and the well, several immediate and long-term measures had to be taken to avoid future waterborne disease outbreaks. The most important precondition was setting up a water quality monitoring system at the Miskolc-Tapolca waterworks to monitor water quality constantly and to enable immediate intervention in case of contamination (including the appearance of turbid water, changes in conductivity, in pH value, in UV absorption calibrated to COD and TOC values, and in the free chlorine level). A second chlorine check was

established 1,050 m away from the feeding point of the water. The system runs preliminary bacteriological tests and daily tests of the untreated and treated water alike for the indicators required for karstic aquifers (ammonium, nitrite, chloride). The waterworks eventually has its own microbiology laboratory. ÁNTSZ have set limit values to facilitate the evaluation of preliminary coliform tests as the current regulations did not provide limit values for untreated water. The waterworks' plan for self-monitoring was broadened to include more frequent microscopic and bacteriological tests. Standard bacteriological tests must be conducted weekly at all karstic aquifers and at all feed points into the mains, while rapid bacteriological and chemical tests have to be conducted daily. Technical and organizational measures were taken, and new Rules of Operation including measures in an emergency were agreed. The pipe work underwent priority check-ups and a complete check of the sewage network throughout the area of Miskolc-Tapolca was carried out. Also, compliance of waste management and livestock farming with regulations has been checked. The possible sources of aquifer contamination were investigated. Two priority tasks for aquifer protection were identified aiming at covering the sinkholes and controlling the water level of an artificial lake.

ÁNTSZ approved the reopening of wells at the Miskolc-Tapolca waterworks on 13 December 2006, underlying several conditions to avoid further waterborne disease outbreaks. The water had to be supplied to the mains in a multiphase manner after rinsing each section of it, and following satisfactory bacteriological tests confirming appropriate water quality. Drawing on lessons from the contamination event, ÁNTSZ is obliged to immediately report any exceedence of limit values of any tested parameters. Priority for future development should be given to an appropriate treatment technology at the Miskolc-Tapolca waterworks and for securing the safety of the aquifer. The waterworks was put back in operation on 20 January 2007, and was fully operational in 3–4 weeks, under continuous monitoring of water quality.

CONCLUSION

The karstic water sources are particularly vulnerable to extreme weather conditions; consequently active protection of karstic aquifers is an important requirement to avoid waterborne disease outbreaks. Constant monitoring of water quality is indispensable; fast tests need to be introduced to check for common contaminants to karstic water aquifers (ammonia, nitrites, chloride). A rapid bacteriological test should be used for coliform/*E. coli* bacteria. The check-monitoring of waterworks needs to be expanded. Appropriate treatment technologies managing emergency situations should be in place. If these conditions are fulfilled, there is a high probability that waterborne diseases can be avoided.

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First received 15 September 2008; accepted in revised form 1 October 2009. Available online 29 January 2010