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Incidence of faecal contaminations in chlorinated and non-chlorinated distribution systems of neighbouring European countries

Beate Hambsch, Karin Böckle and J. Hein M. van Lieverloo

ABSTRACT

Data on *E. coli* incidence in drinking water samples have been evaluated for 4 European countries. Within the EC project MicroRisk, large volume sampling was done in the United Kingdom (with disinfectant residual), the Netherlands (mainly without disinfectant residual) and Germany (without disinfectant residual). No *E. coli* were found and very low background concentrations ($< 10^{-4}$ per L) were calculated. Furthermore, data of 280,000 water samples collected in France (with disinfectant residual), the Netherlands and Germany (both with and without disinfectant residual) were evaluated for *E. coli* incidence. In total, similar results were obtained for Germany and the Netherlands. In France, significantly higher incidences occurred as more small rural supply systems were included. The detailed data evaluation revealed a slight increase of mean *E. coli* concentrations during distribution in Germany and the Netherlands, for both disinfected and non-disinfected supply zones. This suggests that, if technical measures are taken to avoid contamination during distribution, non-disinfected supply zones can be regarded as being as safe as disinfected supply zones. Furthermore, the indicator principle of *E. coli* for faecal contaminations is valid in non-disinfected supply zones. In chlorinated systems, on-line-monitoring of chlorine residuals represents a good means to detect ingress of organic material.

Key words | background contamination, disinfectant residual, distribution system, *E. coli*, finished water, outbreaks

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INTRODUCTION

Drinking water is monitored for the presence of *E. coli* as it is currently among the only variables feasible to test periodically for the presence of faecal contaminations. *E. coli*, however, is not a good indicator of faecal contamination and the presence of faecal pathogens in all cases. If *E. coli* is present, it is likely that faecal pathogens are present, but if *E. coli* is absent, it is not equally likely that faecal pathogens are absent as well (Ashbolt *et al.* 2001). The infection risks during detected faecal contamination events can be calculated from the incidence and concentrations of *E. coli*, but the uncertainty distributions of these infection risks are very wide (Van Lieverloo *et al.* 2007a).

In 2002 the EC project MicroRisk (EVK1-CT-2002-00123) started with the objective to deliver a harmonised, scientifically based framework for quantitative assessment of microbiological safety of drinking water in the EU member states, from source to tap (MicroRisk Final Report 2006). Within this project, data on faecal contamination incidents and the incidence of *E. coli* (or thermotolerant coliforms) in distribution systems in France, the Netherlands, Germany, the United Kingdom and Australia were evaluated (Van Lieverloo *et al.* 2006). In this regard, 22 water companies from the Netherlands, Germany, France, the UK and Australia provided data on *E. coli*

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measurements in drinking water at the end of the treatment, in distribution reservoirs and in the supply zones at consumers' taps for a 3 year period. To detect possible background contamination below the normal detection limit of 1 *E. coli* per 100 mL, high volume samples were collected in Germany, the UK and the Netherlands. The data were evaluated with regard to the situation in the individual countries and the impact of disinfection on the incidence of positive *E. coli* samples.

Disinfection in Germany

The German Drinking Water Directive (German DWD) (Anon 2001*a*), as the national implementation of the EC Drinking Water Directive (98/83/EC) (Anon 1998), does not have the compulsory requirement to disinfect or to distribute with disinfection residuals.

As a general requirement, the German DWD states that the water intended for human consumption has to be free from pathogens, wholesome and clean. This requirement is regarded to be fulfilled if the acknowledged rules of technology are used during water catchment, treatment and distribution and the drinking water quality at least complies with the limit values for microbiological, chemical and indicator parameters.

The microbiological requirements state that pathogens must not be present in concentrations that constitute a potential danger to human health and the minimum requirements set out in Annex 1 have to be met (*E. coli*, enterococci and coliform bacteria all 0/100 mL). An addition states that, in distribution systems where the microbiological requirements can only be met by disinfection, a disinfection capacity has to be guaranteed as a precaution.

Only those substances that are published in a list which is kept up-to-date by the German UBA (Umweltbundesamt) are to be used for treatment and disinfection. This list also includes the maximum dosage of disinfectants, the maximum value after treatment and the minimum value for disinfectants after treatment. The requirements for disinfectants according to this list are summarised in Table 1.

For disinfectant residuals in the distribution system, only chlorine or chlorine dioxide can be used. The concentrations according to these regulations can range from 0.1 mg/L to 0.3 mg/L for free chlorine and from 0.05 mg/L to 0.2 mg/L for chlorine dioxide. These concentrations are comparably low and are not maintained very long during distribution. For instance, the WHO Guidelines recommend a minimum value of 0.5 mg/L for free chlorine. In general, most water utilities prefer the distribution with low or zero disinfectant residuals, as the German consumers complain about the taste and odour from chlorine in drinking water.

Table 1 | Requirements concerning disinfection procedures according to § 11 list of the German DWD

Disinfectant	Minimum value after treatment (0.5 h)(mg/L)	Maximum addition (mg/L)	Limit value after treatment (mg/L)	
Chlorine	0.1	1.2 (6.0)	0.3 (0.6)	free chlorine
			0.01 (0.05)	THM
Chlorine dioxide	0.05	0.4	0.2	chlorine dioxide
			0.2	chlorite
Ozone	–	10	0.05	ozone
			0.01	THM
UV	400 J/m^2	–	–	

A survey in 1991 including around 1,000 water utilities showed that more than 50% use no disinfection procedure at all, and those who used a disinfection procedure mostly used chlorine (Haberer 1994).

Depending on the raw water quality, disinfection has or has not to be part of the treatment. Faecally polluted raw waters (for instance, surface water) always have to be disinfected and additional particle removal can be required to guarantee effective disinfection. In contrast, raw waters without faecal pollution, for instance groundwaters from well protected aquifers, need no disinfection. This so-called primary disinfection of polluted raw waters can be done by chlorine, chlorine dioxide, ozone or UV.

In Germany the main water source (ca. 65%) is groundwater, therefore a lot of these well protected waters need no primary disinfection at all. The long retention time during the subsurface passage reduces bacterial numbers and therefore no pathogens are found in such waters. The aerobic groundwaters often need no treatment at all. When anaerobic groundwaters are used, normally the removal of iron and manganese is necessary, but mostly again no disinfection is needed.

The disinfection for distribution requires disinfectant residuals. This so-called secondary disinfection can only be done by chlorine or chlorine dioxide. There are mainly two reasons for distributing the water with disinfectant residuals. Firstly, to have a safeguard against contamination during distribution (in reservoirs, during pressure losses, construction works in the system, etc.) and secondly, to prevent regrowth.

In Germany, the first aspect should normally be guaranteed by constructive and technical measures in the network management, thus preventing contamination during distribution and not relying on controlling it by disinfectant residuals. Depending on the extent of the contamination the residual might not be sufficient anyway.

Technical rules to prevent secondary contamination are given for instance in DIN 2000 (Anon 2000*a*), DIN 1988 (Anon 1988), EN 1717 (Anon 2001*b*), DVGW W291 (Anon 2000*b*) and DVGW W300 (Anon 2003).

In the Netherlands, the situation is very similar to that described for Germany.

Reported waterborne outbreaks

For the years 1990–2004 a total of 86 water-borne outbreaks of enteric disease were reported in 10 of the 25 EU countries (Risebro *et al.* 2006), 2 of which happened in Germany. Most of the outbreaks were identified in England (34%), followed by Finland (14%), France (8%) and Sweden (8%).

The predominant agent isolated in the outbreaks was *Cryptosporidium* (32%) and the majority of the outbreaks related to *Cryptosporidium* occurred in England. The bulk of the Campylobacter and Norovirus outbreaks (82%) were identified in the Nordic countries, Finland and Sweden.

One of the 2 outbreaks in Germany was a Giardiasis outbreak in 2000 (8 cases of illness) (Gornik *et al.* 2000) in a small water supply in a rural area, treating vulnerable groundwater and spring water only by chlorination. The distributed water was contaminated by surface runoff. During the outbreak investigations *Giardia lamblia* as well as *E. coli* were detected in water samples. The second outbreak was a Norovirus outbreak in 2003 (88 cases of illness) (Anon 2004) which could be shown to be caused by a cross-connection to a cistern that was partly filled with surface water.

Overall, an equal number of surface water and groundwater supplies were implicated in the outbreaks in the 10 EU countries, but groundwater supply outbreaks reported a greater number of cases of illness (43,517) than surface water supplies (23,047). Of the 54 outbreaks where a pathogen could be isolated from cases and the source of the supply was known, 89% of surface water outbreaks were of protozoan origin compared to 46% of groundwater outbreaks.

Detecting contamination events

Confirmed outbreaks show the tip of the iceberg. Many smaller contamination events are likely to occur. These events may even lead to illness in the community supplied, without a link being made to the water system. Evidence that contamination events occur much more frequently than outbreaks is provided by the statutory monitoring of drinking water for *E. coli* (formerly also determined as thermotolerant coliforms). Bartram *et al.* (2002) evaluated the results of monitoring of thermotolerant coliforms in drinking water samples in European countries and suggested that, on average, the percentage of samples showing the presence of thermotolerant coliforms in drinking water from public systems is around 1–2% (range 0–12%). Mendez *et al.* (2004) showed that other indicators of faecal contamination (Clostridium spores, somatic coliphages, F-RNA phages and Bacteriodes fragilis phages) may be present in (chlorinated) tap water in which no *E. coli* is detected. Several outbreaks of viral and protozoan illness occurred through water that met the *E. coli* standard of absence in 100 mL (Anderson & Bohan 2001), as *E. coli* is more sensitive to chlorine than some viral and especially the protozoan pathogens. So, especially in chlorinated tap water, the frequency of *E. coli* detection is likely to underestimate the frequency of faecal contamination. But in most distribution system outbreaks (75%), total or faecal coliforms were also detected during the outbreak investigation (Craun & Calderon 2001).

The presence of bacteria indicative of faecal contamination is a very powerful indication of the possible presence of faecal pathogens and therefore of a risk to public health. But, of course, only small sample volumes (100 mL) are tested, resulting in higher detection limits than in larger sample volumes. Furthermore, the combination of distribution hydraulics, sampling frequency and sampling volume renders the probability of detecting even large faecal contaminations very low (Van Lieverloo *et al.* 2007*b*).

E. coli and faecal enterococci are regarded as the best indicators for faecal contaminations (Köster *et al.* 2003) and are embedded in the EU Drinking Water Directive (Anon 1998) and statutory monitoring programmes for *E. coli* in distributed water exist in all Member States.

RESULTS AND DISCUSSION

Reported incidence of *E. coli*

The official report to the consumers on the quality of water intended for human consumption in Germany (Anon 2005) for the years 2002–2004 was published in December 2005. It covers all water supplies that deliver more than 1,000 m^3/d (or serve more than 5,000 people). These are, in total, 2,700 water supplies and they supply about 60 million people in Germany, or 73% of the total population. The rest of the population is supplied by non-public or smaller water supplies. The volume distributed annually amounts to 4,100 million m^3. In this report the given percentage of *E. coli* positive samples lies between 0.11–0.23%.

In Table 2 these data from Germany are presented together with the data from UK, that are published on www.dwi.gov.uk, and data from water companies from the Netherlands and France. France has a majority of small rural water systems (60% of them supply less than 500 inhabitants and 90% less than 5,000 inhabitants). Germany has a large number of medium-sized mostly municipal water companies whereas in the UK and the Netherlands the situation is more centralised.

In the UK, the water is distributed with comparatively high disinfectant residuals, whereas in France a maximum of 0.1 mg/L chlorine residual is generally observed in distribution systems. In Germany and the Netherlands mostly no residuals are present during distribution, as was discussed before. The reported percentage of *E. coli* positive samples was highest in France (between 0.203–0.492%) and lowest in the UK (between 0.019–0.027%).

Background concentrations

Water companies verify the effectiveness of measures to prevent contamination of drinking water during distribution by structured sampling distribution networks periodically and, for example, after repair work or installation of new pipes. The statutory monitoring of *E. coli* in distributed drinking water is conducted in all Member States of the EU. The EU Drinking Water Directive regulates the sampling frequency for *E. coli* at the tap in premises. The sampling frequency depends on the volume of water distributed in the supply zone. *E. coli* is seldom found in tap water in EU Member States (Table 2).

The rare detection of *E. coli* in tap water, where a repeat sample is negative, could be the result of (a combination of):

- Contamination during sampling or in the laboratory. This cannot be completely excluded, but quality assurance in the laboratory should be rigorous and as long as the quality assurance does not indicate that errors have occurred, the results have to be considered to represent the tap water quality.
- Low level continuous or semi-continuous contamination of tap water as a result of insufficient treatment or ingress/leaks in the distribution network.
- Unnoticed and transient contamination events.

If 2 was the dominant reason, an increase in the sample volume would result in an increase in the frequency of *E. coli* detection. This hypothesis was tested within the framework of the MicroRisk project.

Over 300 large volume samples (6–200 L, as compared to the statutory 100 mL) were collected from supply zones in Germany, the Netherlands and the United Kingdom and analysed for the presence of *E. coli* (Table 3). Samples were taken in urban and rural supply zones, in supply zones

Table 2 | Overview on the incidence of *E. coli* in the UK, Germany, the Netherlands and France (modified from Van Lieverloo *et al.* 2006)

Country	**United Kingdom**			**Germany**			**The Netherlands**			**France**		
Origin of data	***www.dwi.gov.uk***			**Official report to EC**			**Water companies**			**Water companies**		
Number of water companies	**26**			**2,706**			**9**			**2**		
Year	**2001**	**2002**	**2003**	**2002**	**2003**	**2004**	**2001**	**2002**	**2003**	**2001**	**2002**	**2003**
Number of inhabitants (million)	52.7	52.7	53.3	–	–	60.1	12.1	12.1	10.4	27.5	27.1	27.8
Volume distributed annually (million m^3)	5,709	5,768	5,84	–	–	4,112	845	846	766	2,681	2,681	2,681
Percentage of all inhabitants per country in table	89%	89%	90%	–	–	73%	74%	74%	64%	46%	46%	47%
Mean annual volume distributed per inhabitant (m^3)	108	109	110	–	–	68	70	70	74	97	99	96
Mean annual volume distributed per water company (million m^3)	220	222	225	–	–	2	94	94	85	1,341	1,341	1,341
Total number of samples investigated (thousand)	559	556	550	144	144	157	47	47	44	4	27	51
Total percentage of samples with *E. coli*	0.027	0.024	0.019	0.233	0.233	0.106	0.110	0.083	0.072	0.203	0.492	0.233

where groundwater and treated surface water is distributed, both in chlorinated and unchlorinated supply zones and at sampling sites in different parts of the distribution systems. In Germany, only one supply zone was sampled in which deep groundwater treated by three different plants is distributed. In all three plants only iron and manganese is removed and no disinfection procedure is applied.

No *E. coli* was found in any of the samples collected. The results show that a background level of *E. coli*, if present at all, is very low in the investigated distribution systems; between $< 1.4 \times 10^{-5}$ and $< 7.8 \times 10^{-5}$ CFU (colony forming units) per 100 mL, depending on the total volume analysed (Table 3). This strongly suggests that the occasional presence of *E. coli* in samples collected as part of periodical monitoring is the result of a contamination event.

E. coli detection in periodical samples from finished water and from distribution systems

Within the EC project MicroRisk data from statutory monitoring programmes for *E. coli* were also collected to gain information on the incidence of faecal contamination in finished water after treatment, in distribution reservoirs and in tap water from premises. In total the results from over 280,000 samples were compiled and evaluated, representing 3 years of monitoring from 2,100 supply zones of 22 water companies which supply in total about 45 million inhabitants in France, the Netherlands, Germany, the United Kingdom and Australia (Van Lieverloo *et al.* 2006) (Table 4).

In the following, the evaluation of the data for finished water after treatment and tap water from premises (distribution systems) are discussed for France, the Netherlands and Germany. For the UK and Australia no further evaluation was performed, since only limited data from two water companies and supply zones were available.

From the 13 water supply zones in Germany, 6 were distributing water using groundwater, 3 spring water, 3 surface water and 1 bank filtrate as a raw water source. This represents the situation in Germany very well, where about 65% of the water supply is based on groundwater, around 15% on bank filtrates and recharged waters and around

Table 3 | Programme for large volume sampling to detect the background level of *E. coli* in supply zones in Germany, the Netherlands and the UK (from Van Lieverloo *et al.* 2006)

	Germany	Netherlands	United Kingdom
Sampling period	July 2003 – Jan. 2004	Dec. 2003 – Oct. 2004	July 2003 – July 2004
Sampling intervals	All sites weekly	c. 2 per 2 weeks	All sites biweekly
No. supply zones	1	5	2
No. sampling sites	5	18	7
No. samples	$5 \times 26 = 130$	44	$7 \times 26 = 182$
Sample volumes (1)			
- Minimum	6	30	10
- Median	10	200	10
- Maximum	10	200	10
-Total	1,280	7,062	1,820
Samples with *E. coli*	0	0	0
Detection limit (CFP/L)*	7.8×10^{4}	1.4×10^{4}	5.5×10^{-4}
Chlorine residual	none (in all samples)	none (in > 95% of all samples)	0.05 – 0.55 mg/L (in 95% of all samples)

*Detection limit = 1/total volume of samples

Table 4 | Evaluated numbers of water companies, supply zones, inhabitants and *E. coli* samples collected during the 3 year period between 2000 and 2003 (modified from Van Lieverloo *et al.* 2006)

				Number of samples collected			
Country	Water companies	Supply zones	Inhabitants (in million and % per country)	Finished water after treatment	Distribution reservoirs	Tap water from premises	Total
France	2	1,960	27.5 (46%)	21,453	11,252	61,117	93,822
Netherlands	9	125	12.1 (74%)	39,454	1,599	107,593	148,646
Germany	9	13	5.8 (7.1%)	20,737	8,820	12,530	42,087
Un. Kingdom	1	1	0.22 (0.4%)	1,095	545	1,283	2,923
Australia	1	1	0.05 (0.3%)	159	99	674	932
Total	22	2,100	45.7	82,898	22,315	183,197	288,410

15% on surface waters. From the analysed 13 supply zones, 5 distribute the water with disinfectant addition at the end of treatment (Cl_2 or ClO_2) and 8 without any disinfectant addition. In the Netherlands 118 of the 125 supply zones distribute water without disinfectant addition while in France all of the 1,960 supply zones distribute water with disinfectant addition at the end of treatment.

In 10 of the 13 supply zones in Germany no *E. coli* was detected within the 3 year period (Table 5). In system no. 5, 3 single hits occurred, in system no. 10 one single hit (after repair work) occurred. Only in system no. 13 did a real incident occur, where all positive *E. coli* samples were detected within the same timeframe of around 10 d in July 2001 and only in the distribution system. During this incident no positive E. *coli* samples were detected in the finished water after treatment.

In Germany a total of 26 *E. coli* positive samples occurred in 3 of all 13 supply zones (including the one with the incident), which equals 0.06% of all samples. When disregarding the incident in supply zone 13 and looking only at "single hits", then *E. coli* was only detected in 4 samples or in 0.01% of all samples.

The incidence of positive *E. coli* samples in finished water and in distribution systems in France, the Netherlands and Germany is summarised in Table 6.

Only in France were similar percentages of positive *E. coli* samples calculated for finished water (0.3%) and for

Table 5 | *E. coli* detection in 13 German distribution systems between 2001 and 2003 (BF: bank filtrate, SW: surface water, SP: spring water, GW: groundwater)

Supply zones						
No.	**Raw water**	**Volume in $10^6\,m^3$ per year**	**Inhabitants**	**Disinfectant**	**Total number of samples 2001–2003**	**Number of positive *E. coli* samples**
1	BF	55	571,600	0.05 mg/L $C1O_2$	8,702	0
2	SW	22	300,000	0.25 mg/L $C1_2$	4,695	0
3	SW	6.5	98,000	0.20 mg/L $C1_2$	815	0
4	SW	90	3,000,000	0.14 mg/L ClO_2	8,844	0
5	SP/GW	9	140,000	0.20 mg/L $C1_2$	1,590	3 (in first sample; plant, reservoir and tap)
6	GW	54	600,000	–	6,783	0
7	GW	34	400,000	–	3,008	0
8	GW	26	400,000	–	1,090	0
9	GW	9.6	110,000	–	1,885	0
10	GW	4.3	82,000	–	2,057	1(in first sample; reservoir)
11	SP	0.27	2,500	–	445	0
12	SP	0.2	1,600	–	366	0
13	GW	4	80,000	–	2,140	14*(in first samples; tap) 8* (in second and third samples; tap)
Total		314.9	5,785,700		42,420	26

*Incident, over 10 days in July 2001

Table 6 | Number and percentage of samples with positive *E. coli* detection (in first samples) in finished water and in the distribution system during the 3 year period between 2000 and 2003 (data from Van Lieverloo *et al.* 2006)

	Samples with positive E. coli detection Number (total number)%		
Country	**Finished water**	**Distribution system**	**Total**
France	66 (21,453) 0.3%	193 (61,117) 0.3%	262 (82,570) 0.3%
Netherlands	17 (39,545) 0.04%	99 (107,593) 0.09%	116 (147,138) 0.06%
Germany	1 (20,737) 0.005%	15 (12,530) 0.1%	16 (33,267) 0.05%
Total	84 (81,735) 0.10%	307 (181,240) 0.17%	394 (262,975) 0.15%

the distribution system (0.3%), whereas in Germany and the Netherlands the percentage of positive *E. coli* samples in distributed water (0.1% and 0.09%) was higher than in finished water (0.005% and 0.04%).

Overall, the percentage of positive *E. coli* samples in finished water and in the distribution system was significantly higher in France than in Germany and in the Netherlands. A reason might be that in the French data a lot of small rural supply systems are included, which is not the case in the Dutch and German data. The data from the official German report, where many small supply systems are included as well, also show higher incidences (0.11–0.23%, see Table 2).

For every supply zone in Germany and the Netherlands, the mean *E. coli* concentration in finished water and in the distribution system was calculated by dividing the total number of CFU in all samples by the total volume of all samples. If none of the samples contained *E. coli*, the concentration of one sample was considered to have been 0.1 CFU per 100 mL. This was not possible for the French data because of the non-representative small supply zones.

Figure 1 shows the cumulative percentage of inhabitants in the investigated supply zones in Germany and the Netherlands theoretically exposed to the calculated mean *E. coli* concentrations.

The graphs show that the calculated mean *E. coli* concentrations per water supply zone were slightly higher in the Netherlands than in Germany. This was the case for finished water and for distributed water. In Germany 8 out of 13 (62%) and in the Netherlands 118 out of 125 (94%) were non-disinfected distribution systems.

The mean calculated *E. coli* concentrations below which 50% and 90% of all inhabitants were exposed in the investigated supply zones in Germany and the Netherlands, can be derived from Figure 1 (by finding the values of the series line at these *x*-axis percentages) and are presented in Table 7.

In the Netherlands and in Germany 90% of all inhabitants were theoretically exposed to mean *E. coli* concentrations below 0.0009, respectively 0.0007, CFU per 100 mL in finished water and 0.05 and 0.02 CFU per 100 mL in distributed water.

As already discussed above (see Table 6) the German and Dutch data suggest that the quality deteriorates from finished water to the distribution system.

Comparison of *E. coli* detection in periodical samples in supply zones with and without disinfection

In France, all of the investigated supply zones distribute water with disinfectant residuals. In Germany and the Netherlands only 38% and 6% of the evaluated supply zones distribute the water with disinfectant residuals. The disinfection dose in all disinfected supply zones ranged from 0.04 to 0.5 mg/L Cl_2.

The percentages of *E. coli* positive samples were calculated for both disinfected and non-disinfected supply zones of each country (Table 8).

In disinfected supply zones similar percentages of *E. coli* positive samples were calculated for finished water and for the distribution system in Germany (only 1 *E. coli* positive sample each) and in France, whereas in the Netherlands, a higher percentage of *E. coli* positive samples was found for the distribution system compared to the finished water.

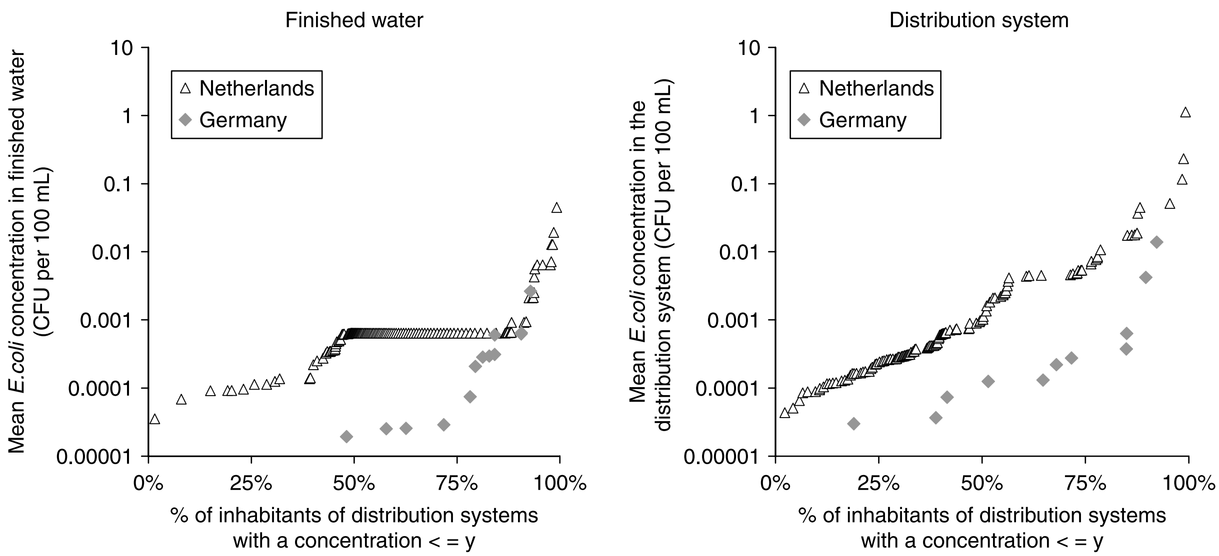

Figure 1 | Mean *E. coli* concentrations per supply zone (total number of CFU in all samples divided by the total volume of all samples) and cumulative percentage of inhabitants exposed to these *E. coli* concentrations in supply zones within the Netherlands and Germany (left: in finished water; right: in the distribution system).

Table 7 | Mean *E. coli* concentrations in finished water and in the distribution system below which 50% and 90% of all inhabitants in the evaluated supply zones in the Netherlands and Germany are exposed

	50% of inhabitants exposed to a mean *E. coli* concentration below in CFU per 100 ml		90% of inhabitants exposed to a mean *E. coli* concentration below in CFU per 100 ml	
Country	**Finished water**	**Distribution system**	**Finished water**	**Distribution system**
Netherlands	0.0007	0.002	0.0009	0.05
Germany	0.00003	0.0002	0.0007	0.02

Table 8 | *E. coli* detection (in first samples) in finished water and in the distribution system of supply zones with and without disinfection during the 3 year period between 2000 and 2003

	Samples with positive *E. coli* detection Number (total number) %			
	with disinfection		**without disinfection**	
Country	**Finished water**	**Distribution system**	**Finished water**	**Distribution system**
France	66 (21,453) 0.3%	193 (61,117) 0.3%	–	–
Netherlands	0 (7,522) 0%	30 (30,296) 0.1%	17 (29,012) 0.06%	69 (77,297) 0.09%
Germany	1 (1,243) 0.08%	1 (5,296) 0.02%	0 (6,923) 0%	14 (7,234) 0.2%
Total	67 (30,308) 0.2%	224 (96,709) 0.2%	17 (35,935) 0.05%	83 (84,531) 0.1%

In the non-disinfected supply zones similar percentages of *E. coli* positive samples were calculated for finished water and for the distribution system in the Netherlands, whereas in Germany a higher percentage was calculated for the distribution system.

Figure 2 shows the cumulative percentage of inhabitants in the Netherlands and Germany theoretically exposed to mean *E. coli* concentrations, calculated for finished water (left) and for distribution systems (right) of disinfected (bottom) and non-disinfected supply zones (top) of all investigated supply zones. The number of disinfected supply zones was quite low in both countries.

The mean *E. coli* concentrations below which 90% of all inhabitants of the respective supply zones were exposed are given in Table 9. For the disinfected supply zones as well as for the non-disinfected supply zones highest mean *E. coli* concentrations can be found in the distribution system. In the non-disinfected supply zones the mean *E. coli* concentrations are only slightly higher than in the disinfected supply zones (factor 2–3).

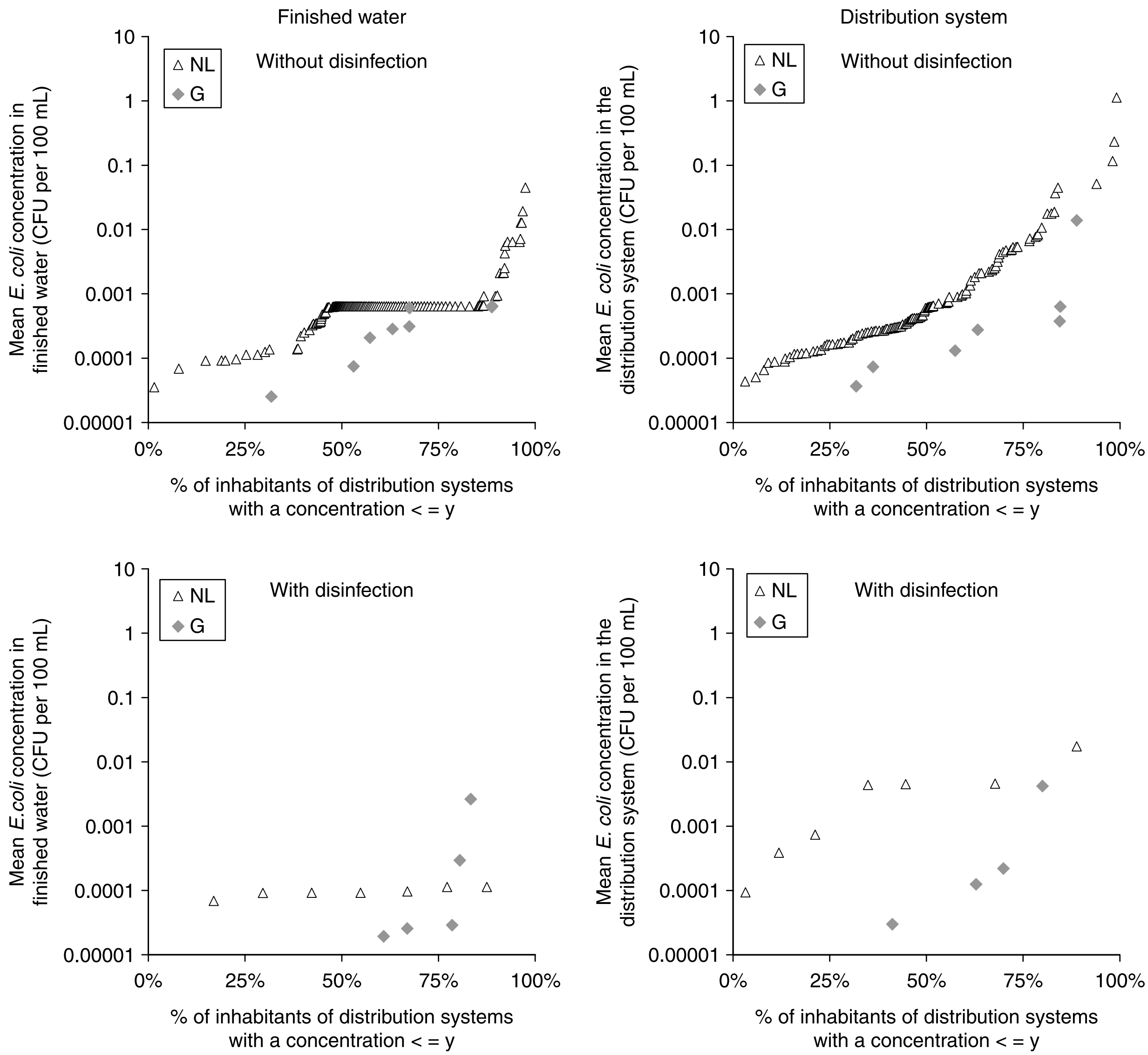

Figure 2 | Mean *E. coli* concentrations in finished water (left) and in the distribution system (right) per supply zone in the Netherlands and Germany (total number of CFU in all samples divided by the total volume of all samples) and cumulative percentage of all inhabitants per country exposed to these *E. coli* concentrations in supply zones with (bottom) and without (top) disinfection.

Table 9 | Mean *E. coli* concentrations in finished water and in the distribution system below which 90% of inhabitants of the Netherlands and Germany are exposed in supply zones with and without disinfection

	90% of inhabitants exposed to a mean *E. coli* concentration below in CFU per 100 mL			
	with disinfection		without disinfection	
Country	Finished water	Distribution system	Finished water	Distribution system
Netherlands	0.0001	0.02	0.0009	0.05
Germany	0.003	0.004	0.0007	0.01

Health consequences

It is very hard to deduct health consequences from *E. coli* incidence found in drinking water. Even when disinfectant residual concentrations are equal, the uncertainty about the source of the faecal contamination leads to very wide uncertainty distributions, although it might provide an indication of the possible health consequences when the contamination source is known (Van Lieverloo *et al.* 2007*a*). The health consequences can only be estimated with an acceptable degree of certainty when the pathogen to *E. coli* ratios in the actual contamination source are determined and survival of both pathogens as well as *E. coli* in the drinking water can be estimated as well. But in most cases, the contamination source is not found and if it is, its composition has often changed since the contamination started. Therefore, the mentioned preconditions are rarely met. As the health consequences depend on the pathogen to *E. coli* ratios in the contamination sources and the relative survival in the distributed drinking water, more research into pathogen to *E. coli* ratios in common and actual contamination sources is called for.

CONCLUSIONS

- The results of large volume sampling to detect low background contaminations showed very low numbers for *E. coli* ($< 8 \times 10^{-4}$ per L), if present at all. This suggests that occasional *E. coli* detection during periodical monitoring is most probably caused by a contamination event.
- Results of detailed evaluation of thermotolerant coliform and *E. coli* monitoring data showed the highest percentage of positive samples was calculated for France, where only disinfected water is distributed, including an overproportional number of small supply systems. This could be suggestive of a higher risk of non-compliance related to small rural systems supplying extensive areas with low density populations, compared to highly centralised systems supplying large concentrated populations.
- For the Netherlands and Germany, where both disinfected and non-disinfected water is distributed, an increase of mean *E. coli* concentrations from finished water to the distribution system was observed. The distributed water showed similar mean *E. coli* concentrations and percentage of *E. coli* positive samples in disinfected and non-disinfected supply zones.
- Altogether, the data evaluation of *E. coli* incidence suggests, firstly, that the presence of chlorine residuals in the distribution system on its own is not sufficient to ensure water safety and, secondly, that if technical measures are taken to avoid cross-connections, pressure losses, etc., a high level of safety can also be ensured in non-disinfected distribution systems. In the latter case, the indicator principle of *E. coli* for faecal contaminations is valid, and contaminations can be recognised. In chlorinated systems, ingress of organic material can be detected by on-line monitoring of chlorine residuals.
- If the water companies strive for a high distribution system integrity, i.e. low water losses to reduce the danger of pressure losses and good quality management for repair work to reduce contamination during works in the distribution system, non-disinfected supply zones can be as safe as disinfected supply zones. This is especially an advantage if chlorine-resistant pathogens can be present in the respective raw waters.

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