International report: water and wastewater disinfection – trends, issues and practices

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Abstract The prevention of waterborne diseases since the early part of this century can be attributed, in great part, to routine disinfection of water and wastewater. Issues surrounding disinfection differ from country to country. The objective of this paper is to provide an international report on water and wastewater disinfection practices. A background and history of disinfection is presented, followed by a discussion of microorganisms of concern in water and wastewater, disinfection practices, and issues and developments in specific countries. Additionally, selected similarities and differences between water and wastewater disinfection practices will be discussed. The information presented is based, in part, on the national reports on disinfection of water and wastewater that were submitted by 22 countries (Table 1); other information cited was obtained from the literature.

Keywords Chlorination; disinfection; disinfection byproducts; efficacy; International Report; microbial pathogens

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Background and history

Disinfection has its roots as a water treatment technique in the latter part of the nineteenth century. As early as 1881, Koch, a German, demonstrated the role bacteria play in waterborne disease and demonstrated that small amounts of chlorine could effectively "kill" or inactivate pathogenic bacteria. The first continuous use of chlorination for disinfection of drinking water occurred on continental Europe in Middelkerke, Belgium in 1902, and later was practiced in Lincoln, England in 1905 (Whipple, 1906; Houston, 1913). In the United States, the use of chlorination was first initiated in Louisville, Kentucky in 1896. The first continuous application to drinking water in America occurred in 1908 at the Boonton Reservoir, which served as a water supply for the water works of Jersey City, New Jersey (White, 1999). These applications used solid calcium hypochlorite or a bleaching powder. Soon thereafter, liquid chlorine gas became available, making large scale, continuous chlorination more easily implemented. The first permanent facility using liquid chlorine gas was installed at Philadelphia in 1913 and at Rye Common in England in 1917. These early applications of chlorine were installed to address serious contamination or to avoid filtration; however, in the following three decades the practice of chlorination was rapidly expanded to include most surface water supplies, including those that were filtered. By World War II, disinfection with chlorine had become a treatment standard around the world.

The existence of chloramines was first recorded by Dulong in the nineteenth century and subsequently studied by others (Thernard and Berthollet, 1813; Armstrong, 1890). Rideal (1918) was the first to employ these compounds intentionally as biocides. Race (1918), who found that taste and odors were reduced when ammonia and chlorine were added together, adopted this method in 1916 at the principal water treatment plant for Ottawa, Ontario. The first chloramination facility in the United States was established in Denver, Colorado, and the first regular application of ammonia with chlorine took place in 1926 in

Greenville, Tennessee (McAmis, 1927). Chloramination was employed frequently between 1929 and 1939. However, soon thereafter, this practice declined because of the shortage of ammonia during World War II and the elucidation of the breakpoint phenomenon (White, 1999).

The development of wastewater disinfection paralleled the disinfection of water. The first application of chlorination of wastewater was reported by Soper in England in 1879 when chlorinated lime was employed to treat feces of patients with typhoid (White, 1999). On a plant scale, chlorination was first used in Hamburg, Germany in 1893 in response to a typhoid epidemic. The adoption of chlorine for wastewater disinfection was slow due to the deterioration of chlorinated lime in storage and operational difficulties. However, the development of a liquid chlorinator in 1913 and an understanding of basic principles of wastewater chlorination encouraged its more widespread use (White, 1999).

Historically, the use of chlorine for disinfection has been contentious. Many of its opponents argued for the use of protected supplies in place of disinfection (Drown, 1893–4). More importantly, there has always been a natural aversion to the use of chlorine, due to its impact on the aesthetic qualities of drinking water. Largely for this reason, primary disinfection with ozonation became the process of choice in much of continental Europe in the late 1960s and throughout the next decade. In the mid-70s, researchers in Holland (Rook, 1974) and in America (Bellar *et al*., 1974) demonstrated that free chlorine reacts with natural organic constituents in water to produce chlorinated organics, specifically the trihalomethanes. Consequently, regulators began to set limits on the trihalomethanes in finished drinking water (USEPA, 1979; WHO, 1996; EU, 1998). Since then, by-products have been identified with other disinfectants and limits have been set on many of these as well (USEPA, 1998). It is likely that chemical by-products are formed any time an oxidant is employed in water treatment, many of these to be the target of future regulation (Trussell, 1993).

In the 1980s the protozoan, *Giardia lamblia* was identified as an important waterborne pathogen. Over the past decade another protozoan, *Cryptosporidium parvum,* has been shown to be an important source of waterborne disease (Rose *et al*., 1997). Both of these organisms were found to be resistant to traditional chemical disinfectants (Rose *et al*., 1997). Consequently, a renewed emphasis on physical removal of these microorganisms developed. In the 1990s, low-pressure membrane filtration was shown to be effective for removal of protozoan cysts and oocysts (Jacangelo *et al*., 1991; Jacangelo *et al*., 1995). Since then, numerous treatment plants have been installed (USEPA, 2001). In recent years, a photochemical process, ultraviolet irradiation, has been demonstrated to be very effective for inactivating *Giardia* and *Cryptosporidium* (Craik *et al*., 2001). As a result, there is increasing anticipation of its use in drinking water for disinfection. However, chlorine remains the dominant drinking water disinfectant today and disinfection remains the cornerstone of water treatment where public health is concerned.

What is disinfection?

The paramount goal of water and wastewater treatment is to protect public health. From that point of view, the focus of treatment is on the prevention of disease through the reduction of pathogens by processes that either remove or inactivate them. This reduction should be to a degree that neither the water nor the wastewater serves as a conduit or vector for the transmission of disease in the community. Consequently, treatment should ensure that water produced is microbiologically safe or "disinfected."

It is important to note that disinfection is also a treatment process(es) employed to *reduce* risk of disease by biological or physiochemical methods that either *remove* the pathogens or *inactivate* them. Processes that reduce pathogen risk by inactivation (as opposed to removal) have traditionally been called "disinfection". It is likely that the term disinfection was borrowed from the medical community where chemicals were used to disinfect hands, instruments and working surfaces. Chlorine, one of these chemicals, was shown to be very effective in inactivating bacteria in drinking water; as such, it soon became accepted that all drinking waters (and many wastewaters) must be disinfected. It is also inferred that these waters must be made microbiologically safe. Historically, processes for inactivating pathogens were several orders of magnitude more effective than processes for removing them. One could not be assured that a contaminated water supply had been made microbiologically safe unless it had received disinfection; a water that was "disinfected" became synonymous with one receiving "disinfection".

In recent years, many new treatment processes have been emerging. Some of these processes, such as membrane filtration, have the potential to be more efficacious in reducing pathogens through physical removal as compared to inactivation. More importantly, the performance of each disinfection process varies substantially among organisms, whereas membrane filtration processes primarily discriminate among organisms by their size. For example, the product of disinfectant concentration and contact time (*Ct*) for 99% inactivation of *Cryptosporidium parvum* with chlorine is three orders of magnitude higher than the *Ct* required for 99% inactivation of *Escherichia coli*. By comparison, membrane filtration removes both organisms by greater than 99.999% (Jacangelo *et al*., 1995). In the past, water was made microbiologically safe with a disinfection process; physiochemical processes were considered those that improved the performance of the disinfection itself. Today, however, there are operating plants that produce "disinfected" water with membranes (Yoo *et al*., 1995; USEPA, 2001).

Microorganisms of concern

Microorganisms of concern can be broadly categorized into the three groups: bacteria, viruses and protozoa (Table 1). It should be noted that macroorganisms, such as algae and nematodes, also present water quality concerns; however, they will not be discussed in this paper. Figure 1 shows specific microorganisms in water supplies that are of concern to countries that provided national reports. Organisms of greatest concern are the protozoa, *Giardia* and *Cryptosporidium*. Between 50 and 60 percent of the countries reported these organisms to be a significant microbial issue. Bacteria were the next more prevalent organisms of concern; 47 and 33 percent of the countries listed *Legionella* and *Campylobacter* as important organisms, respectively. Among the viruses, hepatitis and calicivirus were reported be of most concern.

While the organisms discussed above were of concern to a variety of countries, surrogates or indicators are used for regulatory monitoring (Figure 2). Almost all countries providing national reports (93 percent) used total coliform bacteria for regulatory

Table 1 Important waterborne pathogens

Bacteria	Viruses	Protozoa
Campylobacter	Hepatitis A	*Giardia*
Escherichia coli	Reovirus	*Cryptosporidum*
Salmonella	Calicivirus	*Entameoba*
Yersinia	Enterovirus	*Microsporidium*
Vibrio	Coxsackievirus	
Legionella	Adenovirus	
Aeromonas	Echovirus	
Mycobacterium	Poliovirus	
Shigella		
Pseudomonas		

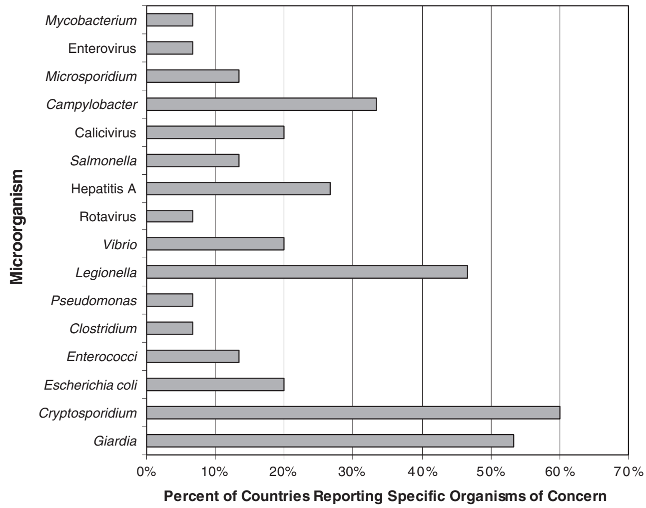

Figure 1 Specific microorganisms in water supplies that are of concern to countries providing national reports (Note: percents do not add up to 100 since, in some cases, more than one microorganism is reported.)

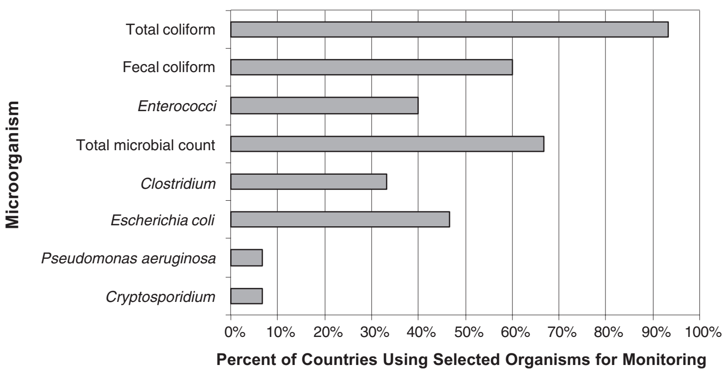

Figure 2 Various types of microorganisms employed by countries for regulatory monitoring in drinking water (Note: percents do not add up to 100 since, in some cases, more than one microorganism is reported.)

monitoring. However, total microbial counts (67 percent), fecal coliform bacteria (60 percent) and *Escherichia coli* (47 percent) were also used by a substantial number of countries. One country directly monitors for *Cryptosporidium* in their finished water.

Fewer organisms are employed for regulatory or process monitoring in wastewater practice among the countries providing national reports. Figure 3 presents the types of microorganisms employed for regulatory or process monitoring in various wastewater effluents. Similar to drinking water monitoring, total coliform bacteria are the indicator used by the greatest number of countries (33 percent), followed by fecal coliform bacteria, *Escherichia coli* and fecal streptococci.

Disinfectant efficacy and use

The primary methods of microbial inactivation in water and wastewater include free chlorine, chloramines, chlorine dioxide, ozone and ultraviolet irradiation. Other lesser-used disinfectants, particularly in wastewater, include formic acid, peracetic acid and bromine chloride. Physical and physiochemical removal processes are also employed for disinfection purposes; examples include granular media filtration and membrane filtration. Table 2

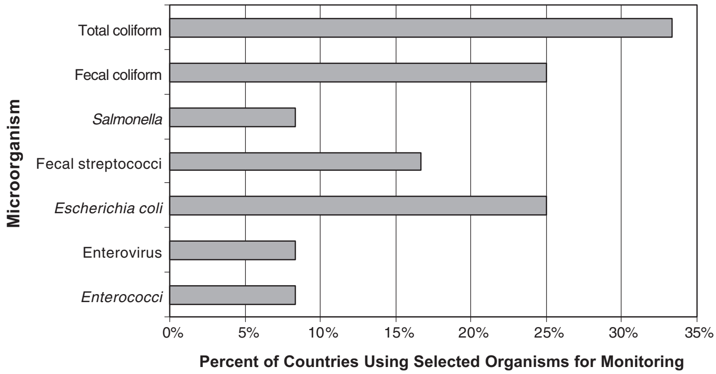

Figure 3 Various types of microorganisms employed by countries for regulatory or process monitoring for a variety of types wastewater effluents (Note: percents do not add up to 100 since, in some cases, more than one microorganism is reported.)

shows a broad, qualitative presentation of the relative effectiveness of these disinfectants and filtration processes for three categories of organisms: bacteria, viruses and protozoan cysts.

Free chlorine, chlorine dioxide, ozone and ultraviolet irradiation are well established, effective treatments for bacteria. Given the contact time and appropriate dosage, chloramines can provide adequate inactivation of bacteria. In addition, granular media filtration, with optimized pretreatment, can provide substantial removals of these organisms. Membrane filtration has the capability to remove bacteria to the detection limits of their respective assays.

For viruses, chloramine and ultraviolet irradiation are more limited in their disinfection efficacy than for bacteria, while chlorine, chlorine dioxide and ozone are very effective. Granular media filtration can remove 2 to 3 logs of viruses, provided that sweep floc is formed in the process. Membranes that have pore sizes less than 0.01 μm can remove viruses to detection limits.

For protozoan cysts and oocysts, ozone, ultraviolet irradiation and membrane filtration are effective, although chlorine dioxide is probably also acceptable. Free chlorine is only fair against *Giardia* and ineffective for *Cryptosporidium* oocyst inactivation. Chloramines are poor cysticidal agents.

Figure 4 presents the types of water disinfectants or disinfection processes employed by countries providing national reports. All of the countries reported having facilities that

Table 2 Comparison of microbial inactivation or removal efficacy by selected disinfectants or filtration processes. (Adapted from Trussell, 1993)

	Bacteria	Viruses	Protozoa	Overall rating
Disinfectants				
Free chlorine	Excellent	Excellent	Fair/Poor	Good
Chloramines[1]	Fair	Poor	Very Poor	Poor
Chlorine dioxide	Good/Excellent	Good/Excellent	Fair	Good
Ozone	Excellent	Excellent	Good/Excellent	Good/Excellent
Ultraviolet irradiation	Good/Excellent	Fair	Good	Good
Filtration Processes				
Granular Media Filtration[2]	Good	Fair	Good	Good
Low-Pressure Membrane Filtration[3]	Excellent	Excellent	Excellent	Excellent

[1]Assumes insitu chloramination, not preformed chloramines
[2]Assumes pretreatment with coagulation and settling processes
[3]Assumes a membrane with a 0.01 μm nominal pore size

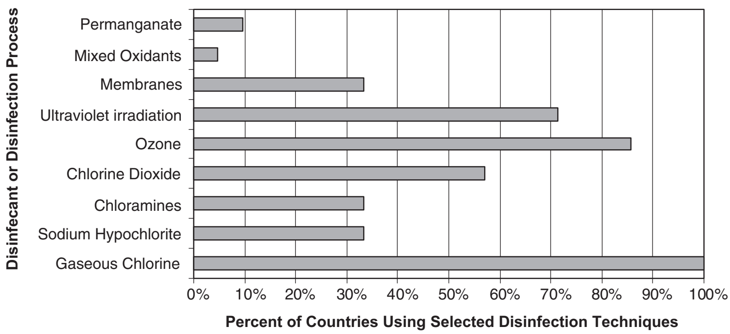

Figure 4 Types of water disinfectants or disinfection processes employed by countries providing national reports (Note: percents do not add up to 100 since, in some cases, more than one disinfection process is reported.)

employ gaseous chlorine, although several are evaluating alternatives because of by-products formed due to its application in water and because of safety issues associated with its handling. Hypochlorite was often mentioned in the national reports as an alternative to meet safety demands. Over 85 percent of the countries reported having ozone facilities. It is also noteworthy that 71 percent of reporting countries had ultraviolet irradiation as a disinfection process; however, over 90 percent of these installations were listed as small in capacity. As noted above, membrane filtration is very effective for microbial removal. Consequently, its use has expanded substantially over the past decade as demonstrated by the number of countries reporting to have installations (33 percent).

In wastewater, a greater variety of disinfectants are employed (Figure 5). Gaseous chlorine and ultraviolet irradiation were employed by most countries. Seventy percent of the total number of countries have facilities using these disinfectants. However, between 20 and 35 percent of countries reported having facilities using ozone, hypochlorite or membranes. A number of other disinfectants or disinfection processes are also being used, including formic acid, peracetic acid, trichloroisocyanuric acid, bromine chloride and heat treatment.

Disinfection by-products

By-products are formed when disinfectants are applied to water under a variety of conditions. In short, the reaction can be described by:

$$\text{Disinfectant} + \text{Precursor} \rightarrow \text{Disinfection By-Products (DBPs)}$$

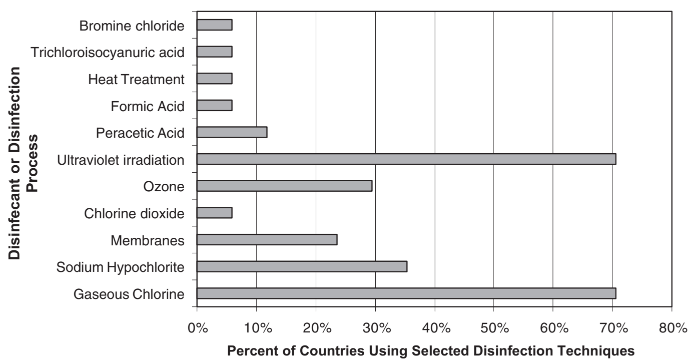

Figure 5 Types of disinfectants or disinfection processes employed by countries for a variety of wastewater effluents (Note: percents do not add up to 100 since, in some cases, more than one disinfectant is reported.)

All of the major chemical disinfectants, including chlorine, chloramines, ozone and chlorine dioxide, form various types of DBPs. These disinfectants react with precursor materials that are comprised primarily of different types of natural organic material and bromide. The formation of DBPs is influenced by various water quality conditions such as temperature, contact time, disinfectant dose and residual. Table 3 shows the major DBPs found in drinking water as a result of disinfection practices (Krasner, 1999). Some of the DBPs listed are formed through halogen substitution, while others are the product of oxidation.

Many drinking water utilities must balance the provision of good disinfection without forming excessive DBPs in finished drinking water. A significant concern in developing regulations for disinfectants and DBPs is the need to ensure that adequate treatment is maintained for controlling risks from microbial pathogens. Thus, it is important to reduce the level of exposure from disinfectants and DBPs without undermining the control of microbial pathogens. In this manner, drinking water will be microbiologically safe at the limits set for disinfectants and DBPs.

Of all the DBPs shown in Table 3, only a few are regulated. Figure 6 shows various DBPs in drinking water currently or proposed to be regulated in countries providing national reports. Sixty percent of the countries reported having regulations or guidelines for trihalomethanes, which are primarily formed through the reaction chlorine with natural organic matter. A few countries regulate individual trihalomethanes. A European Union

Table 3 Major disinfection by-products commonly found in drinking water (from Krasner, 1999)

Trihalomethanes	Choroform
	Bromodichloromethane
	Dibromochloromethane
	Bromoform
Haloacetic acids	Monochloroacetic acid
	Dichloroacetic acid
	Trichloroacetic acid
	Bromochloroacetic acid
	Bromodichloroacetic acid
	Dibromochloroacetic acid
	Monobromoracetic acid
	Dibromoacetic acid
	Tribromoacetic acid
Haloketones	1,1-Dichloroacetone
	1,1,1-Trichloroacetone
Haloacetonitriles	Trichloracetonitrile
	Dichloracetonitrile
	Bromochloracetonitrile
	Dibromoacetonitrile
Miscellaneous chlorinated organic compounds	Chloropicrin
	Chloral hydrate
Cyanogen halides	Cyanogen chloride
	Cyanogen bromide
Oxyhalides	Chlorite
	Chlorate
	Bromate
Aldehydes	Formaldehyde
	Acetaldehyde
	Glyoxal
	Methyl glyoxal
Aldoketoacids	Glyoxylic acid
	Pyruvic acid
	Ketomalonic acid
Carboxylic acids	Formate
	Acetate
	Oxalate
Maleic acids	2-tert-Butylmaleic acid

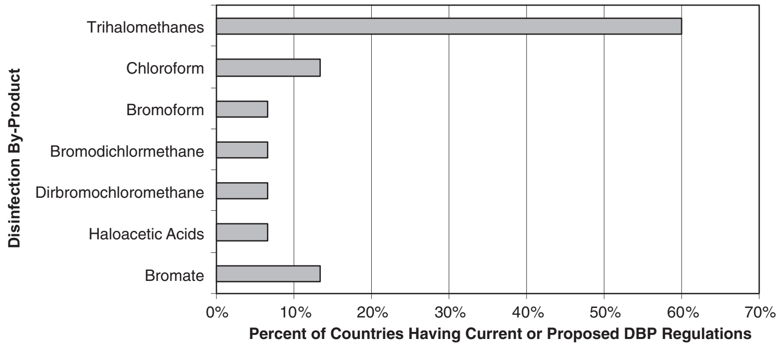

Figure 6 Various disinfection by-products in drinking water currently or proposed to be regulated in countries providing national reports (Note: percents do not add up to 100 since, in some cases, countries regulate more than one DBP.)

1998 directive has set a standard for total trihalomethanes of 150 µg/L; member states must meet this standard by 2003. In 2008, the standard will be lowered to 100 µg/L (EU, 1998). The United States Environmental Protection Agency has promulgated regulations for two classes of DBP compounds: total trihalomethanes and the sum of five specific haloacetic acids; the standards for these compounds are 80 µg/L and 60 µg/L, respectively (USEPA, 1998). Approximately 25 percent of countries have current or proposed regulations or guidelines for bromate, a by-product of the reaction of bromide and ozone. The European Union standard will be 25 µg/L and 10 µg/L based on compliance years of 2003 and 2008, respectively (EU, 1998). The regulation in the United States is 10 µg/L for bromate (USEPA, 1998).

Summary: disinfection trends, issues and practices

This section presents a summary of the major trends, issues and practices identified by countries submitting national reports. Those associated with water disinfection are shown in Table 4. Compliance with regulations is a driving force for water purveyors in selecting disinfectants. There are two key issues in light of regulations: 1) providing good disinfection, and 2) minimizing the production of DBPs. An increased emphasis on disinfection has been stimulated by an increase in reported disease outbreaks, particularly those associated with *Cryptosporidium*. For countries that use chlorination, trihalomethanes are the key by-product of concern; for ozone, the major by-product is bromate (although production of assimilable organic carbon is also an issue).

Chlorine continues to be the major disinfectant used by countries worldwide. However, the resistance of protozoa to chlorine has spurred increasing interest in investigating and employing alternative disinfectants that provide better inactivation efficacy while not producing excessive levels of DBPs. Data from reporting countries show that ozone, chlorine dioxide and ultraviolet irradiation are three of the most often used disinfectant alternatives. However, physical removal processes are also playing a greater role; 33 percent of countries reported using membranes for microbial removal.

Table 5 presents the major trends, issues and practices in wastewater disinfection as identified by countries submitting national reports. Disinfection of wastewater effluent is not mandatory in many countries. However, meeting water quality standards and guidelines in receiving waters is the determining factor of whether or not these countries employ disinfection.

Similar to water disinfection, chlorine is the dominant disinfectant used for wastewater treatment because it is a well established technology that can provide effective wastewater

Table 4 Selected trends, issues and practices in water disinfection reported by specific countries

Country	Trend, Emphasis or Practice
Italy	Increased emphasis on maintenance of a disinfectant residual in the distribution system; establishing limits for chlorite concentration in the distribution system; establishing efficacy of physical removal of microorganisms.
Malaysia	Quality of raw water improving due to environmental strategies adopted; monitoring of *Giardia* and *Cryptosporidium*.
South Korea	Need for installation of advanced disinfection facilities and introduction of disinfection policies (including CTs) anticipated.
Finland	Increased use of ultraviolet irradiation, especially for groundwaters.
Poland	Reduction of assimilable organic carbon removal of sediments/biofilm in the distribution system; maintenance of disinfectant residuals; research on membranes for disinfection; efficacy of chlorine dioxide and ultraviolet irradiation for disinfection.
Romania	Emphasis on assuring microbiological quality of distributed water.
Japan	Emphasis on maintaining trihalomethanes levels while provide good disinfection.
Hong Kong	Emphasis on use of ozone for disinfection and oxidation.
Portugal	Greater use of alternative disinfectants to comply with future DBP regulations; increased monitoring of disinfectant residuals and by-products.
Norway	Emphasis on two hygienic barriers (source water protections and water treatment). Increased use of membrane filtration for disinfection purposes – 62 membrane plants (most NF/RO) in the country.
Slovakia	Emphasis on the hygienic treatment of drinking water.
France	Substantial increase in microbiological quality of distributions systems observed; increased emphasis on balancing DBPs and disinfection, with particular attention to selected pathogens; increased use of membrane filtration and ultraviolet irradiation for disinfection purposes.
Spain	Increased use of alternative disinfectants to chlorine for primary disinfection.
South Africa	Investigation into more effective disinfection practices for larger utilities and introduction of basic disinfection for small communities; increased research activity into membranes and ultraviolet irradiation for disinfection.
United States	Increased emphasis on balancing DBPs and disinfection; increased use of membranes for disinfection; anticipated use of ultraviolet irradiation for disinfection purposes; increased concern over emerging pathogens in drinking water.
Germany	Emphasis on limiting DBPs in finished drinking water; increase use of membrane filtration and ultraviolet irradiation for disinfection.
Hungary	Emphasis on limiting DBPs in finished drinking water by optimizing disinfectant application point; increased use of alternative disinfectants or disinfection processes such as membranes.
Bulgaria	Emphasis on disinfection with chlorine for large systems; use of ozone and ultraviolet irradiation for smaller facilities.
Sweden	Greater focus on ultraviolet irradiation for disinfection; less emphasis on chlorine dioxide as a disinfectant; formulation of guideline for optimization of chlorine use.
United Kingdom	Control of DBPs and pathogens, particularly *Cryptosporidium*, in distributed water; decreased in use of gaseous chlorine; increased use of sodium hypochlorite, ultraviolet irradiation and membranes for disinfection.
Czech Republic	Upgrading of physical/chemical separation process to improve water quality prior to disinfection; increased application of chlorine dioxide and ozone.

disinfection; it also provides a residual that can be maintained. Additionally, chlorination has been historically inexpensive to install and operate. However, there are several disadvantages to employing this disinfectant. While it is possible to maintain a residual, chlorine

Table 5 Selected trends, issues and practices in wastewater disinfection reported by specific countries

Country	Trend, Emphasis or Practice
Italy	Installation of emergency disinfection systems in wastewater plants; research conducted on the use of ultraviolet irradiation, chlorine dioxide, peracetic acid and hypochlorite/hydrogen peroxide for tertiary-treated wastewaters.
Finland	Compliance with hygienic water quality orders.
Romania	Emphasis on rehabilitation of wastewater treatment plants.
Japan	Promotion of alternative disinfection technologies such as ultraviolet irradiation and ozonation; increased emphasis on water quality control of combined sewer overflows.
Hong Kong	Research emphasis on the use of ozone, multi-point dosing of hypochlorite, membrane filtration and electrochemical disinfection; evaluation of applying disinfection after chemically enhanced primary treatment.
Portugal	Emphasis over the past decade on construction of wastewater disinfection systems, particularly ultraviolet irradiation and wastewater stabilization ponds; increased use of alternatives to chlorine for disinfection.
Norway	Assurance of good disinfection of aquaculture facility effluents.
Slovakia	Emphasis on the maintenance of adequate disinfection through use of gaseous chlorine and hypochlorite.
France	Emphais on disinfection of secondary and tertiary treatment effluents.
Tunisia	Increased emphasis on water reuse; use of ultraviolet irradiation.
Spain	Use of ultraviolet irradiation for disinfection of tertiary treated wastewaters; research directed towards wastewater reuse for arid areas using membranes, ozone and ultraviolet irradiation for disinfection.
South Africa	Wastewater research focused on alternative methodologies to control pathogenic protozoa and pathogenic *Escherichia coli*; emphasis on use of ultraviolet irradiation for disinfection.
United States	Increased emphasis on wastewater reuse using membrane for disinfection purposes; increased use of ultraviolet irradiation treatment of secondary effluents.
Germany	Use of ultraviolet irradiation for disinfection of effluents affecting bathing waters; evaluation of membrane filtration for pathogen removal.
Bulgaria	Emphasis on disinfection with chlorine for treated domestic and industrial wastewaters.
United Kingdom	Emphasis on applying ultraviolet irradiation for wastewater disinfection; application of chemically-assisted sedimentation before disinfection; membrane bioreactors installed at two sites.
Czech Republic	Emphasis on use of chlorine to meet microbiological standards from selected facilities; application of thermal treatment employed is select cases.

must often be reduced through dechlorination to avoid toxicity of treated effluents. Like in water disinfection, chlorination of wastewater will cause the formation of trihalomethanes and other chlorinated hydrocarbons of public health concern. Volatile organic compounds from chlorine contact basins may also be released. Additionally, chlorination of wastewater will increase the total dissolved solids and chloride content of the effluent. It should also be noted that although chlorination has been historically inexpensive to practice, many associated safety requirements, such as installing chemical scrubbers and providing 24-hour emergency staff, have increased both its capital and operational costs.

Table 5 shows that many countries are evaluating or using alternative disinfectants. The most used alternative is ultraviolet irradiation; over 70 percent of countries reported using this disinfectant. Based on the many advantages of ultraviolet irradiation disinfection over chlorination/dechlorination, it appears that the use of this technology will continue to increase in the future. It is anticipated that as many chlorine disinfection facilities reach their useful life, they will be replaced with this type of disinfection process. Further, as newer ultraviolet irradiation technology components are developed (e.g., new ballasts or lamps), it is anticipated that capital and operation and maintenance requirements will decrease, making the process even more competitive with traditional disinfection processes.

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