

Drinking water standards in South American countries: convergences and divergences

Vívian Gemiliano Pinto, Léo Heller and Rafael Kopschitz Xavier Bastos

ABSTRACT

In this paper we present a comparative assessment of drinking-water standards from almost all South American countries, using the USA and the Canadian standards and the World Health Organization (WHO) Guidelines as references. Similarities and discrepancies between standards/guidelines were identified through descriptive analyses and, in the case of chemical standards, clustering techniques. In general, one or another of the four consecutive editions of the WHO Guidelines were shown to be quite influential in setting drinking-water standards in the region, but not so much the USA and the Canadian standards. Considerable discrepancies between South American drinking-water standards were found, mainly with respect to chemical substances. Questions are raised about their scientific basis and/or the practicalities for their enforcement. In conclusion, the paper highlights that many drinking-water regulations in South America need updating, taking on the approach of health-based targets in setting these standards, as well as that of a broader risk-based preventive management in the entire supply system to assure water safety.

Key words | drinking-water, regulation, South America, standards

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ABBREVIATIONS

DDBP	disinfectants and disinfection by-products
FCM	fuzzy C-means algorithm
HPC	heterotrophic plate count
MAV	maximum accepted value
MoH	Ministry of Health
QMRA	quantitative microbial risk assessment
TC	total coliforms
ThC	thermotolerant coliforms
NTU	nephelometric turbidity unit
RC	residual chlorine
OSE	Administración de las Obras Sanitarias del Estado
US EPA	United States Environmental Protection Agency
WHO	World Health Organization
WSP	water safety plans

INTRODUCTION

In this era of globalisation, with blocs of nations forming, efforts towards more convergent and harmonised regulatory frameworks among different countries, in various areas of activity, continue to take place. In principle, the convergence of drinking-water standards or regulations is not just a matter of political pragmatism; rather, it is a public health concern and this idea suggests the need for common issues to be observed in any standard. On the other hand, there are strong arguments that an incremental approach towards long-term health-based targets should drive the allocation of resources to improving drinking-water safety; therefore no single approach is universally applicable and it is essential that each country assess its needs and capacities in developing a drinking-water regulatory framework (WHO 2011).

As advocated by the World Health Organization (WHO), the safety of drinking-water is preferably ensured by means of a conceptual framework that encompasses the establishment of health-based targets by health authorities, proper management of water supply systems based on a preventive risk-based approach, adequate monitoring and a system of independent surveillance (WHO 2011). National drinking-water standards and regulations should be seen as part of such a framework, reflecting as much as possible local circumstances, i.e. taking into account environmental, social, economic and cultural issues. Thus, it is anticipated that drinking-water standards and regulations may vary among countries or regions.

The WHO also emphasises that hazards should be prioritised in developing standards and regulations, so that they are readily implementable and enforceable, and at the same time protective of public health. In this sense, the WHO considers that microbial hazards continue to be the primary concern as they contribute most to the burden of disease related to water and sanitation, as compared to most chemical hazards, which have health impacts usually associated with long-term exposure and may have more important exposure routes than drinking-water (Prüss *et al.* 2002; Prüss & Corvalan 2006; WHO 2011).

Bastos *et al.* (2004) have identified major discrepancies between several drinking-water standards in countries within the Americas, casting doubt on what scientific and other background information they are based on, such as: actual occurrence of chemicals and pathogenic organisms in local source and drinking-waters, general epidemiological or toxicological knowledge of human health risks associated with exposure to drinking-water contaminants and corresponding local evidence, local infrastructure and technological capacity as well as the analytical capacity of local laboratory facilities. Questions could also be raised about how up-to-date these standards are in relation to setting health targets based on scientifically sound tools like quantitative microbial risk assessment (QMRA) or burden of disease metrics.

Following the work of Bastos *et al.* (2004), in this paper we present a more comprehensive comparative assessment of South American drinking-water standards, discussing to what extent they are up-to-date and identifying similarities and differences among them. This study focuses entirely

on drinking-water standards or guidelines, i.e. measurable parameters. We acknowledge though that complying with standards, however important it is, is only a sub-component of essential requirements to ensure the safety of drinking-water, like broader regulation and, most of all, the integrated risk assessment and management outlook, as advocated in the WHO's water safety planning approach.

METHODS

Drinking-water standards from South American countries (except Guyana and Suriname) were compared to each other, as well as with those from the USA and Canada, and the WHO Guidelines for Drinking-Water Quality, which are taken as references here. We used the latest version of each country's standards and the last four editions of the WHO Guidelines, because some of the current South American standards are contemporary to one of the previous WHO Guidelines. The country's regulations were catalogued by date and the respective drinking-water standards compiled as follows: (i) microbiological parameters, (ii) turbidity after filtration or before disinfection, (iii) chemicals of health significance (inorganic and organic constituents; pesticides, disinfectants and disinfection by-products) and (iv) substances and parameters that may give rise to complaints from consumers.

Microbiological standards, including turbidity after filtration or before disinfection, were compared on a descriptive basis. Similarities between chemical and aesthetic/organoleptic standards were determined by means of a clustering technique using a fuzzy C-means algorithm (FCM) created with the software Matlab 7 (Santos 2006).

Since the goal of the fuzzy clustering process is to group a set of data into K number of clusters (or homogeneous groups) and the appropriate number of groups is not initially known, it becomes necessary to validate the cluster to determine the optimal number of clusters according to the distribution of the sample.

The clustering algorithm used herein works as follows. Each maximum acceptable value (MAV) (in some cases, guideline values) of the n water quality parameters established in a drinking-water regulation is transformed

into a value between -1 and $+1$ and is represented by a point in an n -dimensional space, n being the number of parameters determined by the regulation under consideration. According to the number of clusters K , determined by validating the clusters, K points are positioned at random in this n -dimensional space. Euclidean measurements are then made from these initial K points to those which represent the drinking-water standard, and grouped with those initial points that have the smallest Euclidean distance.

Based on this initial grouping procedure, the centre of the group is determined using the geometrical coordinates of the points (which represent the drinking-water standards) that belong to this group. Thereafter, the process is repeated iteratively until the change in the distance between the centre of the cluster of the new group and that of the former one is minimal; in the case of the algorithm used here, 0.001.

The clustering algorithm cannot be used with missing data, but the occurrence of such data was inevitable given that the regulations differ a great deal in terms of number of water quality parameters. Thus, we tried to fill in the missing data for each parameter using three approaches: using figures that were one or three decimal places above the highest identified MAV, or -1 . Also, the clustering procedure was tested using: (i) all the drinking-water regulations, (ii) only those regulations which established MAV for the group of water quality parameters under study, assuming that a lack of parameters was itself a similarity between regulations and (iii) only those regulations which established MAV for the group of water quality parameters under study, in addition excluding those parameters that were present in just one set of regulations. After all tests had been conducted, the results that appeared to be least influenced by missing data were used, i.e. those achieved using the third testing procedure above mentioned. The best fit for filling out the missing data appeared to be three decimal places above the highest MAV, meaning that if a given water quality parameter is not regulated, in theory, an infinite concentration of this parameter is allowed.

In summary, by using this clustering algorithm we identified groups of regulations with similar parameters and/or similar MAV.

RESULTS AND DISCUSSION

Regulations

As indicated in Table 1, in most countries evaluated in this study drinking-water standards are part of national/federal regulations or guidelines. The only exception in South America is Argentina, which, like Canada and the USA, has provincial regulations, but based on the federal standard. Also, it should be noticed that drinking-water regulations from South American countries differ greatly with respect to currentness, some of them dating back to mid to late 1990s, while others have been recently revised.

In Paraguay, the national regulations lay down different criteria for water services provided for communities with up to or more than 2,000 connections/10,000 inhabitants. The small-scale services are usually provided by community-managed water associations or small private suppliers (referred to here as 'permit holders' or 'permittees'), whereas the larger services can still be provided by community-managed water associations but primarily by a national public enterprise (referred to here as 'water utilities') (ERSSAN, Paraguay 2002a, b). In Uruguay, drinking-water standards are set forth in two pieces of national regulation in force: one put out by the state owned national utility, *Administración de las Obras Sanitarias del Estado* (OSE), (OSE, Uruguay 2006), and the other by the Ministry of Health (MoH) (Ministerio de Salud, Uruguay 1994).

Microbiological parameters

Table 2 presents a summary of the microbiological standards required by the regulations analysed here. We must initially clarify that the distinction between standards applicable to final treated water samples (water treatment plant output/distribution system input) or samples from the distribution system itself was, in some instances, our own interpretation, since such distinction is not always explicit in the regulations.

In most regulations microbial standards are established in terms of absence of total coliforms (TC), and thermotolerant coliforms (ThC) or *Escherichia coli*. For final treated water samples, the Brazilian regulation is the only one that relies solely on a TC standard, presumably based on the

Table 1 | Drinking-water standards/regulations in South American countries, Canada and the USA: regulations, date and institutional location

Country	Date	Regulation and responsible institution
Argentina	1994	Código Alimentario Argentino (Res MSyAS N° 494 del 7.07.1994) [Argentine Food Code]. Ministry of Health of Argentina and Social Action (Ministerio de la Salud de Argentina y Acción Social, Argentina 1994).
Bolivia	2004	Norma NB512 – Agua Potable. Requisitos [NB 512 Standard – Drinking-water requirements]. Ministry of Services, Vice Ministry of Basic Services (IBNORCA, Bolivia 2004).
	2005	Reglamento Nacional para el control de la calidad del agua para consumo humano [National regulation for drinking-water quality control]. Ministry of Water, Vice Ministry of Basic Services (IBNORCA, Bolivia 2005).
Brazil	2004	Portaria MS n° 518/2004 [Ordinance MS 518/2004] – Ministry of Health. (Ministério da Saúde, Brazil 2004).
Chile	2005	Norma Chilena Oficial NCh 409/1.Of.2005. Agua Potable – Parte 1: Requisitos [Official Chilean Norm NCh 409/1.Of.2005. Drinking water Part 1: Requirements] National Institute of Standardization (INN, Chile 2005).
	2004	Norma Chilena Oficial NCh 409/2.Of.2004. Agua Potable – Parte 2: Muestreo [Official Chilean Norm NCh 409/2.Of.2004. Drinking water – Part 2: Sampling] National Institute of Standardization (INN, Chile 2004).
Colombia	2007	Resolución 2115 de 2007 [Resolution 2115 / 2007]. Ministry of Social Protection and Ministry of Environment, Housing and Territorial Development (Ministerio de la Protección Social, Colombia 2007).
Ecuador	2010	Norma Técnica Ecuatoriana NTE INEN 1108:2010. Agua Potable. Requisitos. [Ecuadorian Technical Standard NTE INEN 1108:2010. Drinking-water. Requirements] Ecuadorian Standardization Institute (INEN, Ecuador 2010).
Paraguay	2000/2002	Ley N° 1614/2000 [Law 1614/2000] (Paraguay 2000), Reglamento de Calidad en la Prestación del Servicio - Concesionarios [Regulation on Service Provision Quality for Water Utilities] (ERSSAN, Paraguay 2002a), Reglamento de Calidad en la Prestación del Servicio - Permisionarios [Regulation on Service Provision Quality for Water for Permittees] (ERSSAN, Paraguay 2002b) and Decreto Reglamentario 18880/2002 [Regulatory Decree 18880/2002] (Ministerio del Interior, Paraguay 2002).
Peru	2010	Decreto Supremo DS N° 031-2010-SA. Reglamento de la Calidad del Agua para Consumo Humano [Supreme Decree DS N° 031-2010-SA. Drinking-water regulation]. Ministry of Health (Ministerio de Salud, Peru 2010).
Uruguay	1994	Decreto 315/994. Agua y Bebidas Sin Alcohol [Decree 315/994. Drinking-Water and Soft Drinks]. Ministry of Health (Ministerio de Salud, Uruguay 1994).
	2006	Normas Interna de Calidad de Agua Potable, OSE, R/D N° 1477/06 [Internal Standard for Drinking Water Quality, OSE, R/D N° 1477/06]. State Water Utility. (OSE, Uruguay 2006).
Venezuela	1998	Normas Sanitarias de Calidad Del Agua Potable [Health Standards for Drinking-Water Quality] Ministry of Health and Welfare (Ministerio de Sanidad e Asistencia Social, Venezuela 1998).
Canada	2010	Guidelines for Canadian Drinking Water Quality – Health Canada (Health Canada 2010).
USA	2009	National Primary Drinking Water Regulations and National Secondary Drinking Water Regulations – United States Environmental Protection Agency – US EPA (US EPA 2009).

understanding that the absence of TC is sufficient to indicate the effectiveness of disinfection processes in inactivating bacteria. All regulations seem to take on the widely accepted approach that *E. coli* (or ThC) should be always absent in the distribution system, since its presence would represent a strong suggestion of treatment failure or water recontamination during distribution. Another widely adopted approach is that TC should be present only in a limited percentage of samples analysed over a given period of time. The underlying assumption here is that TC does not necessarily indicate water contamination in the distribution system, and that findings below a given threshold are an indication of system integrity ([OECD, WHO 2003](#)).

However, specific criteria for verifying drinking water safety in distribution systems are quite varied among the regulations evaluated here. In some of them, TC presence/absence is to be verified monthly, in others yearly, whereas in some cases the period of time is simply not specified. On the other hand, regulations from Argentina, Colombia and Peru do not indicate the percentage of samples that can be positive for TC. The Paraguayan regulation is also unclear, making its enforcement somewhat difficult. The Chilean standards are noteworthy because they indicate that TC may be present in one sample per month if fewer than four samples are analysed in a sector of the distribution network, or in 25% of samples when four or more samples are analysed in that sector.

Table 2 | Drinking-water microbiological standards in South American countries, Canada and the USA regulations and in the WHO Guidelines

Parameter	Water treatment plant output/Distribution system input															
	ARG	BOL	BRA	CHI	COL	ECU	PAR	PER	URU	VEN	WHO 1	WHO 2	WHO 3	WHO 4	CAN	USA
TC	≤3	A	A	A	A	A	A	A	A	A	A	A	-	-	A	A
<i>E. coli</i> or ThC	A	A	-	A	A	A	A	A	A	A	A	A	A	A	A	A
HPC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>P. aeruginosa</i>	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Distribution system																
TC	≤3	-	A	A	A	A	A	A	A	A	A	A	-	-	A	A
<i>E. coli</i> or ThC	A	A	A	A	A	A	A	A	A	A	A	A	A	-	A	A
HPC	≤500	≤500	≤500	-	≤100	-	-	≤500	≤500	≤100	-	-	-	-	-	≤500
<i>P. aeruginosa</i>	A	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-

TC: total coliforms, ThC: thermotolerant coliforms; HPC: heterotrophic plate count (organisms per ml); A: absent in 100 ml; WHO 1,2,3 and 4: 1st, 2nd, 3rd and 4th editions of the WHO guidelines.

The first edition of the WHO Guidelines allowed the entry of untreated water into distribution systems but required the absence of faecal and TC from either treated or non-treated water, respectively in all and 95% of the samples analysed (WHO 1984). In the second edition of the WHO Guidelines, *E. coli* was presented as the preferred indicator for faecal contamination (as compared to TC and ThC), and it was suggested that all water distributed for human consumption should be disinfected to prevent recontamination in the network (WHO 1995). The third edition of the WHO Guidelines maintained its recommendations regarding the absence of *E. coli* or ThC in the input water and in the distribution system but no longer made reference to the use of TC as an indicator. It also emphasised that operational monitoring and risk assessment tools are as important as using indicator organisms in assuring microbial water safety.

Although routine monitoring of distributed water for particular groups of bacteria is rarely considered worthwhile or necessary (OECD, WHO 2003), standards from Bolivia and Argentina also include *Pseudomonas aeruginosa*. This organism is not an index of faecal contamination but may be useful in assessing regrowth in distribution systems. It is an opportunistic pathogen that mainly gives rise to superficial infection following contact with heavily contaminated water (but does not cause enteric infection by ingestion) (OECD, WHO 2003).

The assessment of water quality in distribution systems often includes heterotrophic bacteria counting. The most common standard of 500 CFU ml⁻¹ still seems to come from the understanding that concentrations greater than this interfere with the recovery of coliform bacteria in techniques based on lactose fermentation, whereas newer coliform detection methods based on the metabolism of chromogenic substrates are not prone to this interference. Nevertheless, heterotrophic bacteria counts can be seen as an important auxiliary indicator of water quality, for they provide information about: (i) disinfection failure, (ii) colonisation and biofilm formation in distribution systems (including the presence of opportunistic pathogenic bacteria) and (iii) changes in water quality or problems with the integrity of distribution systems (Bartram et al. 2003). Water utilities can generally achieve low and consistent levels of HPC bacteria in the finished drinking-water (10 CFU ml⁻¹ or less) and this adds assurance that the treatment process is working properly (Bartram et al. 2003), but this

approach is not yet taken in South American drinking water standards.

Table 3 presents turbidity standards for drinking-water found in the regulations analysed in this study. Again, the distinction between turbidity standards as a health-based target or as an aesthetic/organoleptic objective, are sometimes our own interpretation since this is not always clear in the regulations.

Filtered water turbidity is acknowledged as a good indicator of protozoan (oo)cysts removal by filtration, and this is the approach of the USA and the Canadian regulations whose rather strict standards (0.3 NTU) aim to control *Cryptosporidium* (US EPA 2006; Health Canada 2010). It is also recognised that turbidity should be kept as low as possible to ensure effectiveness of disinfection, and this has been properly addressed in the consecutive WHO Guidelines editions. In the first two editions, an average value of 1 NTU, and no single sample above 5 NTU, prior to disinfection were recommended as guidelines (WHO 1995). The third edition suggested that, for effective disinfection, turbidity should be as low as 0.1 NTU (WHO 2004). It is in the fourth edition of the WHO Guidelines that turbidity is more consistently associated with protozoa removal by filtration, stating that large, well-run municipal supplies should be able to average

0.2 NTU or less, and to achieve less than 0.5 NTU before disinfection at all times, and that treatment systems that achieve less than 0.3 NTU prior to disinfection will have demonstrated that they are removing chlorine-resistant pathogens such as *Cryptosporidium* (WHO 2011).

However, except for Brazil, Uruguay OSE, and Paraguay, South American regulations do not explicitly address the turbidity of filtered water, and turbidity is not clearly acknowledged as part of microbiological standards. Therefore, in most regulations turbidity MAV remains relatively permissive. The Chilean case is noteworthy, as the average recommended turbidity is 2 NTU, but single samples with turbidity up to 20 NTU are allowed.

Table 4 presents the minimum concentration of residual chlorine (RC) required by the regulations under study.

The first edition of the WHO Guidelines indicated that effective disinfection required free RC concentrations between 0.2 and 0.5 mg L⁻¹. The second, third and fourth editions recommended that the RC concentrations be greater than 0.5 mg L⁻¹. In most South American regulations a minimum RC concentration of 0.2 mg L⁻¹ in the distribution system is required. In some countries, however, it is accepted that a certain number of samples present RC lower than the minimum value, even null concentration,

Table 3 | Turbidity standards (NTU) in drinking-water regulations from South American countries, Canada and the USA, and in the WHO Guidelines

Standard	ARG	BOL	BRA	CHI	COL	ECU	PAR	PER	URU OSE
Health-based target ^a			1				1		1
Aesthetic/organoleptic objectives ^b	3	5	5	2	2	5	5	5	3
Standard	VEN	USA	CAN	WHO 1		WHO 2		WHO 3	WHO 4
Health-based target ^a		0.3	0.3	1		1		0.1	0.2–0.3
Aesthetic/organoleptic objectives ^b	5	5	5	5		5		5	5

^aTo be verified in water samples after filtration or before disinfection; ^bTo be verified in the distribution system; WHO 1, 2, 3 and 4: 1st, 2nd, 3rd and 4th editions of the WHO guidelines.

Table 4 | Minimum RC requirements (mg L⁻¹) in the distribution system found in drinking-water regulations from South American countries, Canada, the USA, and in the WHO Guidelines

ARG	BOL	BRA	CHI	COL	ECU	PAR	PER	URU (MoH)	URU (OSE)
0.2	0.2	0.2	0.2	0.3	0.3	–	0.5	–	–
VEN	USA	CAN	WHO 1	WHO 2		WHO 3		WHO 4	
0.3	–	–	0.2	0.5		0.5		0.5	

WHO 1, 2, 3 and 4: 1st, 2nd, 3rd and 4th editions of the WHO guidelines.

like the Chilean regulation. Uruguay MoH and Paraguay allow the distribution of untreated water and RC in the distribution system is only a recommendation, in the range from 0.2 to 0.5 mg L⁻¹. Uruguay OSE sets a RC MAV at 2.5 mg L⁻¹ but does not impose a minimum value.

Most South American drinking-water standards do not comment on disinfection control parameters (e.g. pH, and CT values – residual disinfectant at the disinfection chamber output and contact time). The Paraguayan standard for water utilities, the Uruguayan (OSE) and the Ecuadorian standards address the subject, but only superficially and do not include actual requirements, as the Colombian and Brazilian standards do. In contrast, the USA and the Canadian standards require that treatment technologies in place should achieve at least a 3-log and a 4-log reduction and/or inactivation of, respectively, protozoan (oo)cysts and viruses, unless source water quality requires a greater log reduction and/or inactivation. Log-removal credits are attributed to filtration and disinfection processes, based on filtered water turbidity and CT values (US EPA 2006; Health Canada 2010).

Chemical parameters

The standards for chemicals are organised in various ways in the different sets of regulations. Therefore, for the purpose of comparison, we have adopted the structure of the Brazilian drinking-water standard, which, in turn, is based on the second edition of the WHO Guidelines: substances and parameters that may give rise to complaints from consumers, inorganic substances of health significance, organic substances of health significance, pesticides, disinfectants and disinfection by-products.

As shown in Figure 1, the number of chemicals regulated in the standards/guidelines varies widely. Whilst countries like Brazil, Uruguay (OSE), Ecuador and Peru regulate as much as 70–100 chemicals (close, therefore, to the USA standard and the Canadian guidelines), others, as Argentina, Bolivia, Chile Colombia, Paraguay and Venezuela, deal with approximately 40 or fewer substances. It is worth noticing that the Peruvian standard includes a much larger number of parameters than those of other South American countries, even more than are included in the US and Canadian standards and in recent editions of the WHO guidelines. As with the microbiological parameters, water quality

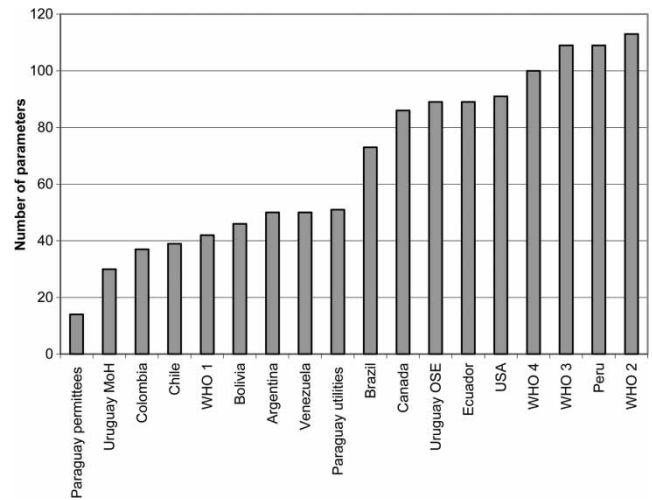


Figure 1 | Number of chemicals included in drinking-water standards from South American countries, the USA, Canada, and in the four editions of the WHO Guidelines.

monitoring is usually focused on the distribution systems, but monitoring frequencies are not always clearly specified.

Substances and parameters that may give rise to complaints from consumers

Figure 2 shows that there are no major discrepancies in the number of aesthetic/organoleptic parameters between most of the drinking-water standards/guidelines evaluated here, except in the case of the Ecuadorian and the

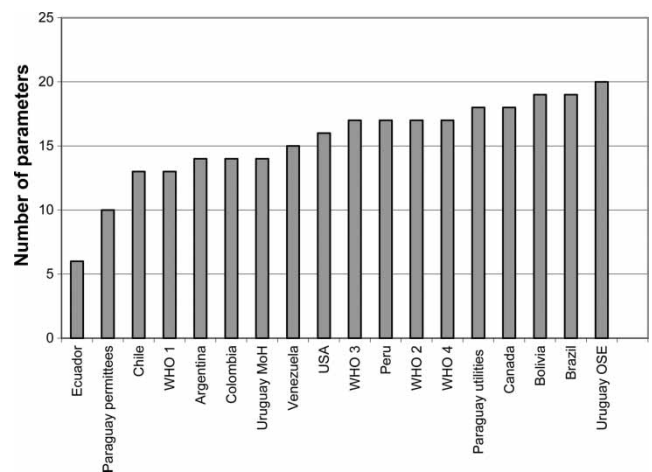


Figure 2 | Number of aesthetic/organoleptic parameters included in drinking-water standards from South American countries, the USA, Canada, and in the four editions of the WHO Guidelines.

Paraguayan regulation for permit holders, which include 6 and 10 parameters respectively, whereas the Uruguayan (OSE) regulation includes 20 parameters.

Before validating the groups (i.e. clusters) for the subsequent grouping of regulations, some harmonisation was necessary, such as: (i) the Bolivian, Brazilian and Chilean standards require measurements of apparent colour, whereas the others require true colour; however, for grouping purposes, this detail was not taken into account; (ii) taste and odour standards are expressed qualitatively and thus were excluded from the analyses; (iii) because pH standards are set in ranges of values, minimum and maximum recommended values were used; (iv) turbidity, as an aesthetic parameter, was not considered here but it was as part of microbiological standards.

After these adjustments and the elimination of those parameters that were present in only one standard/guidelines, 21 parameters were used in the clustering process. Having filled in the missing data using the methods outlined above, we identified five groups in which each standard/guidelines could be fitted in with the membership probabilities shown in Table 5.

The most recurring aesthetic/organoleptic parameters in South American drinking-water standards are: colour, odour and taste, pH and turbidity (which are present in all standards, except pH in the Ecuadorian regulation), aluminium (which is omitted from only the Chilean and Ecuadorian standards); chloride, manganese, total iron and zinc (omitted from only the Ecuadorian and in the Paraguayan standard for permit holders); total hardness (omitted from only the Bolivian, Chilean and Ecuadorian standards); dissolved solids (omitted from only the Colombian and the Ecuadorian standards).

The aesthetic/organoleptic standards and guidelines evaluated in this study were grouped as follows: (i) Ecuador; (ii) Argentina, Uruguay OSE and the first edition of the WHO guidelines; (iii) Brazil, Peru, Canada and the second, third and fourth editions of the WHO Guidelines; (iv) Chile, Uruguay MoH, Venezuela and USA; (v) Bolivia, Colombia, Paraguay – water utilities and Paraguay – permit holders. However, the various standards/guidelines were gathered in a specific cluster at different levels. For instance, the Chilean standard was placed in Group 1 with a low membership probability (41.28%), indicating that its similarities to other standards in the same group is relatively small.

Table 5 | Grouping and membership probabilities for the MAVs of aesthetic/organoleptic parameters present in the drinking-water standards from South American countries, the USA, Canada, and in the WHO Guidelines

Standard/guidelines	Membership probabilities				
	Group 1	Group 2	Group 3	Group 4	Group 5
Argentina	0.0056	0.6480	0.0880	0.1383	0.1200
Bolivia	0.0039	0.0922	0.2473	0.2238	0.4328
Brazil	0.0000	0.0004	0.9965	0.0030	0.0001
Chile	0.0164	0.3104	0.1883	0.4128	0.0721
Colombia	0.0010	0.0222	0.0062	0.0104	0.9601
Ecuador	0.9993	0.0002	0.0002	0.0002	0.0002
Paraguay utilities	0.0007	0.0892	0.0129	0.0181	0.8791
Paraguay permittees	0.1155	0.1520	0.0840	0.1112	0.5373
Peru	0.0049	0.1189	0.4218	0.3878	0.0667
Uruguay OSE	0.0004	0.9491	0.0150	0.0223	0.0131
Uruguay MoH	0.0005	0.0327	0.2725	0.6884	0.0059
Venezuela	0.0003	0.0223	0.1436	0.8300	0.0038
USA	0.0010	0.0382	0.0507	0.9015	0.0086
Canada	0.0006	0.0172	0.5136	0.4639	0.0046
WHO 1	0.0004	0.9210	0.0198	0.0397	0.0190
WHO 2	0.0002	0.0057	0.9344	0.0583	0.0014
WHO 3	0.0000	0.0003	0.9973	0.0023	0.0001
WHO 4	0.0000	0.0004	0.9960	0.0035	0.0001

The Uruguayan (OSE) regulation showed strong similarities with the first edition of the WHO guidelines, with membership probability for the group always higher than 90%. Similarly, the Brazilian standard was strongly grouped with the second, third and fourth editions of the WHO Guidelines, probably because the Brazilian standard and the second edition of the WHO Guidelines are contemporaries, and the subsequent editions do not substantially differ from the second. In effect, the only difference between the Brazilian standard and the second edition of the WHO guidelines for aesthetic/organoleptic parameters is that the former includes total hardness and surfactants, whereas the latter does not.

Inorganic substances of health significance

Most South American drinking-water standards on inorganic substances include between 11 and 17 parameters,

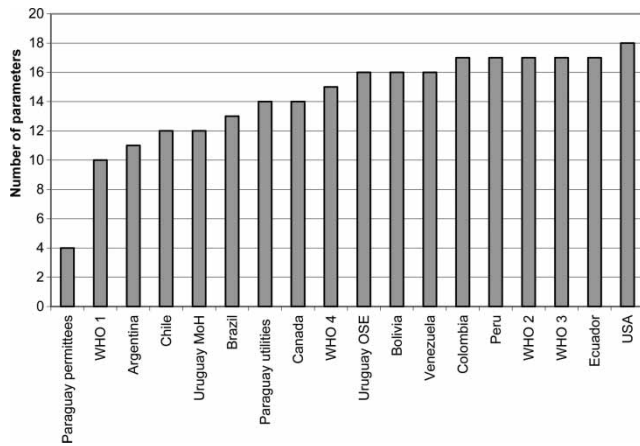


Figure 3 | Number of inorganic substances of health significance included in drinking-water standards from South American countries, the USA, Canada, and in the four editions of the WHO Guidelines.

as shown in Figure 3. The exception is the Paraguayan regulation for permit holders, with only four parameters.

The inorganic substances which were present in only one standard/guidelines were excluded, and the grouping was then carried out using 21 parameters, 14 regulations and the four editions of the WHO Guidelines.

In general, no large discrepancies were identified in terms of MAV for the inorganic substances in the various standards/guidelines. It seems that the MAVs for inorganic substances in the South American standards tend to be similar to those recommended by the contemporary edition of the WHO guidelines.

The validation process indicated that standards/guidelines for inorganic substances of health significance could be separated into four groups (Table 6).

The FCM clustering process allowed us to group the standard/guidelines for inorganic substances of health significance as follows: (i) Brazil, Colombia and the USA; (ii) Bolivia, Ecuador, Peru, Uruguay OSE, Venezuela, Canada and the second, third and fourth editions of the WHO Guidelines; (iii) Paraguay – permit holders; (iv) Argentina, Chile, Paraguay – water utilities, Uruguay MoH and the first edition of the WHO Guidelines.

Although cyanide and molybdenum were excluded from, and four other inorganic parameters had their MAV altered in the fourth edition of the WHO Guidelines, this latest edition was still grouped together with the second and third editions with a relatively high membership

Table 6 | Grouping and membership probabilities for the MAVs of inorganic substances of health significance present in the drinking-water standards from South American countries, the USA and Canada, and in the WHO Guidelines

Standard/guidelines	Membership probabilities			
	Group 1	Group 2	Group 3	Group 4
Argentina	0.2944	0.0792	0.0019	0.6245
Bolivia	0.3150	0.6047	0.0003	0.0800
Brazil	0.9552	0.0124	0.0000	0.0324
Chile	0.0858	0.0215	0.0002	0.8926
Colombia	0.5550	0.2229	0.0014	0.2208
Ecuador	0.0022	0.9972	0.0000	0.0006
Paraguay utilities	0.1985	0.0867	0.0048	0.7099
Paraguay permittees	0.0000	0.0000	1.000	0.0000
Peru	0.0022	0.9972	0.0000	0.0006
Uruguay OSE	0.0126	0.9846	0.0000	0.0028
Uruguay MoH	0.1849	0.0272	0.0005	0.7875
Venezuela	0.2916	0.5969	0.0006	0.1109
USA	0.9350	0.0195	0.0001	0.0453
Canada	0.3092	0.5428	0.0009	0.1470
WHO 1	0.1533	0.0242	0.0004	0.8221
WHO 2	0.0121	0.9853	0.0000	0.0026
WHO 3	0.0022	0.9972	0.0000	0.0006
WHO 4	0.1460	0.7936	0.0009	0.0594

probability (79.36%). The Peruvian, the Uruguayan (OSE) and the Ecuadorian standards were also shown to be quite similar to the three latest editions of the WHO Guidelines, whereas the Bolivian and the Venezuelan standards were placed in this same group, but with weaker membership probabilities. Similarities were also found between the Chilean standard and the first edition of the WHO Guidelines. Not surprisingly, the Paraguayan standard for permit holders could not be grouped together with any other standard or guidelines, because it includes only a small number of regulated substances (four).

Organic substances of health significance

The number of organic substances regulated by each of the standards/guidelines evaluated here varied widely, as shown in Figure 4. The Paraguayan regulation for permit holders does not address these substances at all and the Chilean standard provides MAVs for only three substances,

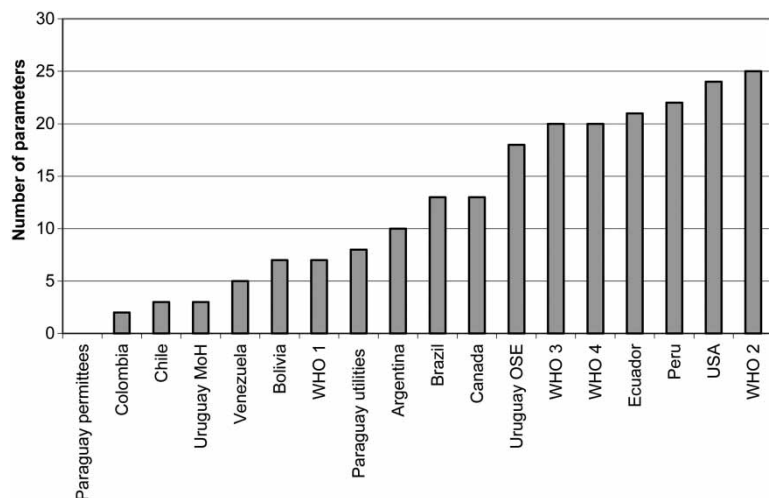


Figure 4 | Number of organic substances of health significance included in drinking-water standards from South American countries, the USA and Canada, and in the four editions of the WHO Guidelines.

whereas the Peruvian standard includes 22 organic substances. Standards and guidelines also differed a great deal in terms of MAVs for organic substances. For instance, the MAVs for 1,2-dichlorobenzene and for 4-dichlorobenzene in Argentina are, respectively, 0.0005 mg L^{-1} and 0.0004 mg L^{-1} , whereas Ecuador and the second, third and fourth editions of the WHO Guidelines indicate 1 mg L^{-1} and 0.3 mg L^{-1} for the former and the latter substances, respectively.

The following regulations were excluded from the FCM clustering process because of the paucity or total lack of organic substances included therein: Chile, Colombia, Paraguay for permit holders and Uruguay (MoH). It was assumed *a priori* that this lack of regulated substances indicated similarity between these standards, but their inclusion would have made it necessary to substitute for a large amount of missing data. Thus, clusters were validated using 28 substances, regulations from ten countries and the four editions of the WHO Guidelines, which were partitioned into five groups, as shown in Table 7.

The following standards/guidelines for organic substances of health significance were grouped: (i) Ecuador, Peru, and the second, third and fourth editions of the WHO Guidelines; (ii) Argentina, Paraguay for water utilities, Canada and the first edition of WHO Guidelines; (iii) Bolivia and Venezuela; (iv) Brazil and Uruguay OSE; (v) USA.

Table 7 | Grouping and membership probabilities for the MAVs of organic substances of health significance present in the drinking-water standards from South American countries, the USA and Canada, and in the WHO Guidelines

Standard/guidelines	Membership probabilities				
	Group 1	Group 2	Group 3	Group 4	Group 5
Argentina	0.0026	0.9875	0.0023	0.0055	0.0021
Bolivia	0.0025	0.0057	0.9846	0.0040	0.0033
Brazil	0.0045	0.0179	0.0038	0.9662	0.0076
Ecuador	0.9927	0.0020	0.0008	0.0029	0.0016
Paraguay utilities	0.0028	0.9729	0.0057	0.0145	0.0042
Peru	0.9706	0.0080	0.0033	0.0120	0.0061
Uruguay OSE	0.0062	0.0062	0.0017	0.9785	0.0074
Venezuela	0.0161	0.1067	0.8174	0.0410	0.0188
USA	0.0000	0.0000	0.0000	0.0000	1.000
Canada	0.0268	0.8938	0.0142	0.0448	0.0205
WHO 1	0.0010	0.9915	0.0024	0.0034	0.0017
WHO 2	0.6710	0.0428	0.0157	0.1481	0.1224
WHO 3	0.9947	0.0015	0.0004	0.0024	0.0011
WHO 4	0.9927	0.0020	0.0008	0.0029	0.0016

In general, standards and guidelines were grouped together with high membership probability within their particular groups, i.e. groups for organic substances were well defined. The only clear exception to this was the relatively weak grouping of the Venezuelan standard within Group 3.

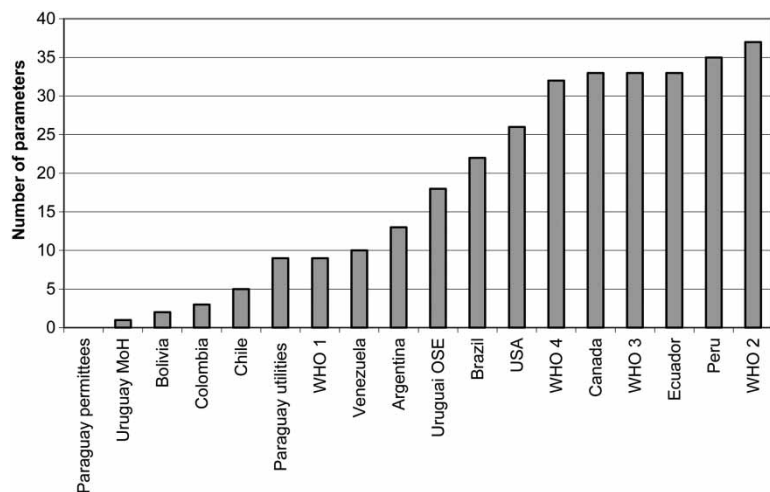


Figure 5 | Number of pesticides included in drinking-water standards from South American countries, the USA and Canada, and in the four editions of the WHO Guidelines.

The Peruvian and the Ecuadorian standards were shown to be very similar to the third and fourth editions of the WHO Guidelines, respectively; as a matter of fact, all substances and their respective MAVs listed in these standards are as recommended in the corresponding WHO Guidelines. The Argentine regulation includes six substances whose MAVs are identical to those recommended by the first edition of the WHO Guidelines, which, in turn, includes only seven substances. However, the Canadian guidelines were also placed in the same group as the first edition of the WHO Guidelines, in spite of them sharing only one MAV. The Argentine standard is closer to the Canadian guidelines; it includes ten substances, all of which are also in the Canadian guidelines, which itself includes thirteen substances. Probably, these two pieces of regulation were grouped together not because they include identical MAVs but because of they have several common substances.

Missing data may have greatly influenced the clustering process. The Venezuelan standard, despite including MAVs identical to those in the second edition of the WHO Guidelines, was probably grouped with the Bolivian standard because they include five and seven substances respectively, of which three are common to these two pieces of regulation. The Brazilian standard was grouped with the Uruguayan (OSE), despite them including, respectively, 10 and 16 MAVs for organic substances that are similar to those in the second edition of the WHO Guidelines.

The clustering seems to have been strongly influenced by the substances included in each piece of regulation and less so by the MAVs. If the grouping was based solely on similarities between MAVs, Brazil, Uruguay OSE, Venezuela and the second edition of the WHO Guidelines would probably belong in the same group. With 25 substances for which MAVs were recommended, the second edition was grouped with the third and fourth editions of the WHO Guidelines, which also includes high numbers of organic substances. It is noticeable though, that the membership probability of the second edition was lower than those of the other group members, probably because 6 of its 25 substances were no longer addressed and 4 had their MAV altered in the fourth edition of the WHO Guidelines.

Pesticides

Figure 5 shows the number of pesticides regulated in the drinking-water standards and guidelines studied here. As with the organic substances, regulation over pesticides varied widely. Once again, the Paraguayan regulation for permit holders does not address these substances at all. The Colombian regulation establishes MAVs for pesticides grouped into low (0.01 mg L^{-1}), medium (0.001 mg L^{-1}) and high (0.0001 mg L^{-1}) toxicity categories. The Bolivian and the Uruguayan (MoH) regulations designate a MAV for total pesticides of 0.0005 mg L^{-1} . The Bolivian standards

indicate that the MAV of each individual pesticide should be 0.0001 mg L^{-1} but emphasises that there are pesticides whose concentration may be lower or higher; it then recommends that WHO and US EPA references be followed. Also, some pieces of regulation address pesticides not included in any other standard or guideline, such as: Canada (11 pesticides), the USA (6), Brazil, and Argentina (1 pesticide each). In the third edition of the WHO Guidelines, the monitoring of various pesticides was deemed unnecessary (this being reinforced in the fourth edition), either because they are unlikely to occur in source or drinking waters or because they occur at concentrations well below those capable of producing toxic effects (WHO 2004, 2011). However, many of these pesticides continue to be regulated in some countries. In brief, not unexpectedly, regulating pesticides seems to be very site-specific.

Having excluded those substances addressed by only one piece of regulation, as well as those standards/guidelines that regulate groups of pesticides instead of individual substances, the remaining ten pieces of regulation and the four editions of the WHO Guidelines (which included 46 parameters) were sorted into five groups (Table 8), as follows: (i) Ecuador, Peru and the third and fourth edition of the WHO Guidelines; (ii) Brazil and Uruguay OSE; (iii) second edition of the WHO Guidelines; (iv) Argentina, Chile, Paraguay for water utilities, Venezuela and the first edition of the WHO Guidelines; (v) USA and Canada.

Standards from Argentina, and Paraguay for water utilities proved to be very similar to the first edition of the WHO Guidelines, most probably because of similarities between both the regulated substances and respective MAVs. The Venezuelan standard was also placed in this same group, showing however lower membership probability. Although Brazil, Chile, Venezuela and Uruguay (OSE) present MAVs for the substances they regulate identical to those of the second edition of the WHO Guidelines, the fact that they regulate many fewer substances (mainly Chile and Venezuela) appears to have brought them into other groups than that of second edition of the WHO Guidelines. The Peruvian and Ecuadorian standards were grouped with the third and fourth editions mainly because of their close similarities in terms of number of substances and corresponding MAVs.

Table 8 | Grouping and membership probabilities for the MAVs of pesticides present in the drinking-water standards from South American countries, the USA and Canada, and in the WHO Guidelines

Standard/guidelines	Membership probabilities				
	Group 1	Group 2	Group 3	Group 4	Group 5
Argentina	0.0034	0.0258	0.0037	0.9460	0.0211
Brazil	0.0010	0.9913	0.0021	0.0038	0.0017
Chile	0.0091	0.0602	0.0077	0.8484	0.0746
Ecuador	0.9959	0.0004	0.0032	0.0002	0.0003
Paraguay utilities	0.0001	0.0021	0.0001	0.9965	0.0011
Peru	0.9910	0.0010	0.0070	0.0005	0.0005
Uruguay OSE	0.0008	0.9892	0.0012	0.0066	0.0023
Venezuela	0.0118	0.1093	0.0111	0.5590	0.3088
USA	0.0019	0.0057	0.0020	0.0071	0.9833
Canada	0.1110	0.1344	0.0985	0.2277	0.4284
WHO 1	0.0001	0.0021	0.0001	0.9965	0.0011
WHO 2	0.0000	0.0000	1.000	0.0000	0.0000
WHO 3	0.9998	0.0000	0.0001	0.0000	0.0000
WHO 4	0.9959	0.0005	0.0030	0.0003	0.0003

In short, the FCM clustering process revealed consistent grouping with respect to both the substances included in the several standards/guidelines and the MAVs specified therein, although the substances seem to have had a greater influence on the clusters.

Disinfectants and disinfection by-products

Figure 6 presents the number of disinfection by-products (DDBP) included in the standards/guidelines analysed herein. Both the Paraguayan (for permit holders) and the Uruguayan (MoH) regulations do not address the subject. Whereas none of the editions of the WHO Guidelines include MAVs for total trihalomethanes, most South American standards do, as do the Canadian guidelines and the USA standards. In Argentina, Brazil, Colombia and Paraguay (water utilities), only total trihalomethanes are regulated. In Bolivia, in addition to total trihalomethanes, a MAV is also set for chloroform.

The regulations from Bolivia and Chile, along with the newly revised regulations from Peru and Ecuador, include MAVs similar to the guideline values of the second, third and fourth editions of the WHO Guidelines, indicating

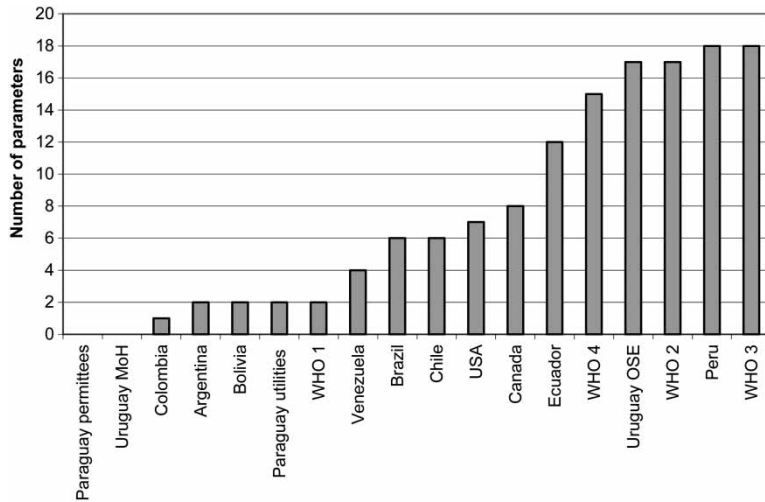


Figure 6 | Number of disinfectants and disinfection by-products included in drinking-water standards from South American countries, the USA, Canada, and in the four editions of the WHO Guidelines.

that the sum of the ratio of the concentration of each individual trihalomethane (bromoform, dibromochloromethane, bromodichloromethane and chloroform) to its respective recommended value should not exceed 1 (WHO 1995, 2004, 2011). On the other hand, for some of the DDBP, large discrepancies between the WHO Guidelines values and MAVs of other standards/guidelines were noted.

As usual, substances that were included in only one piece of regulation, as well as regulations which do not include any or includes only one DDBP, were excluded from the FCM clustering process. Thus, the clustering had 21 substances, pieces of regulation from eleven countries and the four editions of the WHO Guidelines, which were grouped into five clusters (Table 9), as follows: (i) Peru, Uruguay OSE and the second and third editions of the WHO Guidelines; (ii) Ecuador and the fourth edition of the WHO Guidelines; (iii) Argentina, Bolivia, Brazil, Paraguay for water utilities and the first edition of the WHO Guidelines; (iv) USA and Canada; (v) Chile and Venezuela.

Although Venezuela and Brazil have DDBP MAVs rather consistent with those in the second edition of the WHO Guidelines, they were affiliated with groups whose regulations include a similar number of parameters regardless of the required MAV. Similarly, although the Chilean regulation includes MAVs identical to those in the third edition of the WHO Guidelines, it formed a group with the Venezuelan standard, which regulates a similar number of

Table 9 | Grouping and membership probabilities for the MAVs of disinfectants and disinfection by-products present in the drinking-water standards from South American countries, the USA and Canada, and in the WHO Guidelines

Standards/guidelines	Membership probabilities				
	Group 1	Group 2	Group 3	Group 4	Group 5
Argentina	0.0001	0.0001	0.9969	0.0006	0.0023
Bolivia	0.0023	0.0040	0.7889	0.0139	0.1909
Brazil	0.0259	0.0417	0.6221	0.1956	0.1147
Chile	0.0032	0.0054	0.0263	0.0035	0.9616
Ecuador	0.0614	0.9042	0.0104	0.0050	0.0190
Paraguay utilities	0.0001	0.0001	0.9969	0.0006	0.0023
Peru	0.9751	0.0233	0.0005	0.0003	0.0008
Uruguay OSE	0.7771	0.1756	0.0140	0.0101	0.0233
Venezuela	0.0025	0.0063	0.0860	0.0044	0.9008
USA	0.0005	0.0008	0.0046	0.9921	0.0020
Canada	0.0007	0.0011	0.0063	0.9897	0.0022
WHO 1	0.0022	0.0048	0.8271	0.0086	0.1572
WHO 2	0.9463	0.0458	0.0025	0.0016	0.0039
WHO 3	0.9963	0.0035	0.0001	0.0000	0.0001
WHO 4	0.0418	0.9524	0.0017	0.0012	0.0029

DDBP. The Ecuadorian standard and the fourth edition of the WHO Guidelines were grouped together and with no other standard or guideline, and indeed they are quite similar: only 1 out of the 12 DDBP in Ecuadorian standard is not addressed in the WHO Guidelines, and the other

11 substances have the same MAVs as the WHO guideline values. The Peruvian standard includes all DDBP listed in the third edition of the WHO Guidelines, and these two were grouped together with rather strong similarities (membership probability above 97%). The third and fourth editions of the WHO Guidelines were not clustered together, probably due to the exclusion of three substances in the fourth edition and to the change of the MAV for chloroform.

Overall, it can be said that clusters for disinfectants and disinfection by-products were fairly well defined, but this does seem to be more a result of the lack of DDBP in many regulations rather than of actual similarities between regulated DDBP and their respective MAVs.

CONCLUSIONS

Our study suggests that drinking-water regulations from South American countries have been, to various extents, influenced by one or another edition of the WHO Guidelines. On the other hand, it seems that the USA and the Canadian drinking-water regulations have much less influence in South America.

Given the relevance that microbial hazards have in terms of burden of disease related to drinking-water, it is worth noticing that important differences between microbiological drinking-water standards are found in South American countries. Major discrepancies however, do not occur for microbial parameters as such (like the use of coliform bacteria as water quality indicators), but on other complementary indicators. For instance, except for Brazil, Uruguay and Paraguay, there is no explicit standard for filtered water turbidity (which is widely recognised as an indicator of protozoa control) and turbidity MAVs vary widely among regulations. Also, disinfection control parameters (more specifically, CT values) are not addressed by most of the South American regulations.

Remarkable divergences were found for chemicals, both in terms number of regulated substances and, less so, their respective MAVs. It was also noted that whereas standards for both inorganic substances and aesthetic/organoleptic parameters are more comprehensive, several pieces of regulation are tend to omit standards to regulate organic

substances, pesticides and DDBP. The main discrepancies in terms of MAVs were found with respect to organic substances.

Using FCM clustering to identify similar drinking-water pieces of regulation for chemicals, we identified different groups for different classes of substances and clustering seems to have been most influenced by the number of chemicals addressed in each piece of regulation and less by their MAVs.

The fact that South American standards are uncoupled from the USA and Canadian standards may relate to the different institutional set ups, and this aspect deserves more attention. It is also intriguing that, apparently, South American regulations are not necessarily influenced most by their contemporary edition of the WHO Guidelines. Also, local contexts may help to explain some of the disparities encountered (e.g. why particular countries focus on different chemicals) and this also warrant further investigation.

In any case, in spite of the fact that some regulations have been recently revised and apparently were strongly influenced by recent editions of the WHO Guidelines, as far as we could gather, regulations from Brazil (from 2004), Colombia (2007) and Peru (2010) are the only ones that incorporate some of the risk assessment principles of the water safety planning approach, as advocated since the third edition of the WHO Guidelines (from 2004).

In conclusion, this paper highlights important discrepancies between drinking-water standards and regulations in South America, and the information presented here could be used as a starting point for their updating. Whether there is a case for harmonisation efforts across the region remains open to discussion, as drinking-water standards and regulations should, ideally, reflect local circumstances, be enforceable and protective of public health. Moreover, they should be based on achievable health targets, in accordance with the concept of progressive realisation that underlines the new human rights framework for water and sanitation as now advocated by both the United Nations and the WHO. Even more important would be a shift from a static standards-only based approach to drinking-water quality to one of a dynamic integrated risk assessment and management along the entire chain from source to tap.

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