Impact of cemeteries on groundwater contamination by bacteria and viruses – a review

Józef Żychowski and Tomasz Bryndal

ABSTRACT

In the process of decomposition of a human body, 0.4–0.6 litres of leachate is produced per 1 kg of body weight. The leachate contains pathogenic bacteria and viruses that may contaminate the groundwater and cause disease when it is used for drinking. So far, this topic has been investigated in several regions of the world (mainly Brazil, Australia, the Republic of South Africa, Portugal, the United Kingdom and Poland). However, recently more and more attention has been focused on this issue. This study reviews the results of investigations related to the impact of cemeteries on groundwater bacteriology and virology. This topic was mainly discussed in the context of the quantities and qualities of changes in types of microorganisms causing groundwater contamination. In some cases, these changes were related to the environmental setting of a place, where a cemetery was located. The review is completed by a list of recommendations. Their implementation aims to protect the local environment, employees of funeral homes and the residents living in the vicinity of cemeteries. In this form, this review aims to familiarize the reader with the results of this topic, and provide practical guidance for decision-makers in the context of expansion and management of cemeteries, as well as the location of new ones.

Key words | aquifer contamination, cemeteries, groundwater, interments, quality indicator microorganisms

Józef Żychowski (corresponding author)
Tomasz Bryndal
Department of Geography,
Pedagogical University of Cracow,
Podchorążych Street 2,
30-086 Cracow,
Poland
E-mail: *jozyk@wp.pl*

INTRODUCTION

Cemeteries are among the chief anthropogenic sources of pollution and contamination of water in urban areas and beyond them (Silva *et al.* 2011). Many researchers are convinced that all cemeteries represent potential threats to the environment (Rodrigues & Pacheco 2003; Dent 2004). In the process of decomposition of a human body, 0.4–0.6 litres of leachate with a density of 1.23 g·cm^{-3} is produced per 1 kg of body weight (Silva 1995). The leachate contains 60% water and 30% salts in the form of ions containing nitrogen, phosphorus, Cl, HCO_3^-, Ca^{2+}, Na^+, compounds of various metals (e.g., Ti, Cr, Cd, Pb, Fe, Mn, Ni), and 10% of organic substances (Beak Consultants Ltd 1992; Silva 1998; Matos 2001; Żychowski 2008). This liquid is characterized by high conductivity, pH and biochemical oxygen demand (BOD) values, and by its specific fishy odour (Matos 2001). The contaminants come from the body and can include chemical substances applied in chemotherapy and embalming processes (e.g., arsenic, formaldehyde and methanol), makeup (e.g., cosmetics, pigments and chemical compounds), as well as various additional items, such as fillings, cardiac pacemakers, paints, varnishes, metal hardware elements, iron nails, etc. (Silva & Filho 2011; Fiedler *et al.* 2012). These leachates also contain microorganisms that may pollute substrates, surface water and groundwater. The microorganisms chiefly include bacteria, viruses, intestinal fungi and protozoa. They can also originate from other sources, e.g., animals, soil, water and the atmosphere (Trick *et al.* 2001).

The corpses of healthy humans and animals release bacteria, for example, those which form the group classified as total coliform bacteria: *Escherichia coli*, *Enterobacter*, *Klebsiella*, *Citrobacter*, *Streptococcus faecalis*, *Clostridium perfringens*, *Clostridium welchii* and *Salmonella typhi*, and

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human-hosted viruses, e.g., enterovirus (Matos 2001; Dent *et al.* 2004; Castro 2008). In most cases, the contamination of the environment comes from pathogenic intestinal bacteria such as *E. coli* (Singleton 1999; Gleeson & Gray 2002), *Pseudomonas aeruginosa* (Knight & Dent 1998; Dent 1998, 2004), *C. perfringens* (Martins *et al.* 1991), and – in Brazil – even *Salmonella* spp. (Pacheco *et al.* 1991; Braz *et al.* 2000).

Most of these microorganisms accelerate the decomposition of organic matter and they are not pathogenic (De Ville de Goyet 1980). Many pathogens gradually die after the death of the host body as they are not capable of surviving for a long time outside of the host body, especially when environmental conditions are inappropriate (Gerba & Bitton 1984). These include, for example, *Yersinia pestis*, *Vibrio cholerae*, *S. typhi*, *Mycobacterium tuberculosis*, *Bacillus anthracis*, variola virus, hepatitis virus and HIV (human immunodeficiency virus) (Yates & Gerba 1983; Yates *et al.* 1985; Gerba *et al.* 1991; Healing *et al.* 1995; Üçisik & Rushbrook 1988; Cook 1999; Trick *et al.* 1999; De Ville de Goyet 2000; Matos 2001; Morgan 2004; Dent 2004). Therefore, some researchers (Bitton *et al.* 1983; Trick *et al.* 1999) have suggested that the groundwater contamination by bacteria and viruses in cemeteries results from contemporary pollutions. However, some microorganisms are long-living and, in appropriate environmental conditions, can survive in soil profile or in groundwater for some time, e.g., *B. anthracis*, variola virus and *Clostridium* spp. (Yates *et al.* 1985; Haagsma 1991; West *et al.* 1998). The survival period varies (Rudolfs *et al.* 1950; Romero 1970; Creely 2004). Lower temperature, higher soil moisture content associated with lower microbial activity, more alkaline environment, and higher organic matter content are the factors that extend the survival period of these microorganisms (Pacheco 2000), especially in the form of endospores. Creely (2004) states that the survival period of pathogens and saprophytes in the ground is limited to a maximum two to three years. In the case of *V. cholerae* this period is shorter and lasts approximately 4 weeks. However, some microorganisms can survive even up to 5 years and, in this time, they can migrate and reach the groundwater, e.g., *E. coli* (Rudolfs *et al.* 1950; Romero 1970). Usually, the migration time takes from 1 to 4 weeks (Pacheco 1986). Dent (2004) reported that in Australia this process may take up to 100 days. Some investigations suggest that this period may be extended to 6 to 8 months (Silva 1994).

Decomposition of interred bodies causes an increase in microbial activity in the surrounding substrate, associated with the release of persistent organic compounds (Matos 2001). Some of these organic compounds are highly toxic, e.g., putrescine (1,4-butanediamine) and cadaverine (1,5-pentanediamine) (Żychowski 2007; Castro 2008). These compounds can cause highly dangerous infectious disease such as liver inflammation (hepatitis C virus) and typhoid fever (*S. typhi)* (Dent 2000a, 2004; Bocchese *et al.* 2007; Leite 2009). Microorganisms associated with decomposition of interred bodies can also cause other diseases such as tetanus (*Clostridium tetani*), gaseous gangrene (*C. perfringens)*, toxic contamination of food (*E. coli*), tuberculosis (*Mycobacterium tuberculosis*), paratyphoid fever (*Salmonella paratyphi*), bacterial dysentery (*Shigella dysenteriae*) and cholera (*V. cholerae*) (Silva, J. A. F. 2000; Silva, L. M. 2000; Josias & Harris 2004). It is worth emphasizing that bacteria transported by water, like those of the genus *Shigella*, as well as rotaviruses and protozoans of the genera *Entamoeba* and *Giardia*, often cause asymptomatic or serious infections with high mortality rates, particularly among children (Matos 2001).

A brief introduction indicated that cemeteries may have large adverse impacts on groundwater and can be a source of dangerous infectious diseases. So far, this topic has been investigated in several regions of the world (mainly Brazil, Australia, the Republic of South Africa (RSA), Portugal, the United Kingdom and Poland). Most of the studies are presented in Portuguese and for this reason have not yet reached worldwide attention. However, recently the international hydrological community has focused more and more attention on this issue. This study reviews the results of investigations related to the impact of cemeteries on groundwater contamination by bacteria and viruses. This issue was mainly discussed in the context of the quantities and qualities of changes in types of microorganisms causing the groundwater contamination. In some cases, these changes were related to the environmental setting of a place, where a cemetery was located. The review is completed by a list of recommendations. Their implementation aims to protect the local environment, employees of funeral homes and the residents living in the vicinity of cemeteries.

In this form, this review aims to familiarize the reader with the results of this topic, and provide practical guidance for decision-makers in the context of the location of new cemeteries, and the expansion and management of existing cemeteries.

CEMETERIES AND GROUNDWATER CONTAMINATION BY BACTERIA AND VIRUSES – REGIONAL OVERVIEW

Studies in Europe

The adverse impact of cemeteries on groundwater caught the attention of scientists at the end of the nineteenth century. In 1879, the French Society for Hospital Hygiene noticed the relationship between typhoid fever and groundwater contaminated by leachates from a cemetery in Paris (Migliorini 2002). This kind of adverse impact was also confirmed by Mulder in the summer of 1954 (Bouwer 1978). He found somewhat sweet-tasting water and an unpleasant smell exuding from wells situated close to cemeteries in Paris. A more serious consequence was the increased number of typhoid fever cases observed between 1963 and 1967 among people living around a cemetery in Berlin and using the groundwater from its vicinity (Bouwer 1978). In other studies carried out in West Germany in 1972, the groundwater of the alluvial substrate situated 0.5 m from burial sites showed quantities of bacteria 60 times higher than those found in natural water (Bouwer 1978). The quantities of these bacteria decreased rapidly to 8×10^3 CFU·100 ml^{-1} (CFU, colony forming unit) at a distance of 3 metres from the interments, and to 1.8×10^2 CFU·100 ml^{-1} at a distance of 5.5 m from the burial plots.

Contemporary research conducted in England within a nineteenth century cemetery in Nottingham, confirmed the occurrence of bacteria around burial plots (Trick *et al.* 1999). However, the general indicator of the total bacteria numbers at 1.38×10^5 CFU·100 ml^{-1} in the groundwater did not indicate a hazard associated with the cemetery. Similar conclusions were voiced by Trick *et al.* (2001) with respect to the current Danescourt Cemetery in Wolverhampton (Table 1). In the groundwater of this cemetery they did find evidence of intestinal bacteria such as faecal streptococci (*S. faecalis*), *Bacillus cereus, C. perfringens*, *Staphylococcus aureus* and the thermotolerant coliforms. Neither the *Salmonella* spp., nor the enteroviruses and rotaviruses were found. Relatively high levels of *S. aureus* and faecal streptococci (*S. faecalis*) were recorded during long-lasting precipitation periods (Trick *et al.* 2001). *S. faecalis* and thermotolerant coliforms probably originated from the ground surface. *Bacillus cereus* showed a great seasonal variation although it did not appear in all piezometers. In turn, *C. perfringens* was found along the groundwater runoff line from the cemetery (Trick *et al.* 2001). This bacterium is very resistant to adverse environmental conditions and, at favourable temperatures (15 to 45 °C), can proliferate under relatively high redox potential (Corry 1978).

In Portugal, extensive studies were conducted in three cemeteries: Querenc, Luz de Tavira and Seixas. In these places, Rodrigues & Pacheco (2003) found high numbers of, for example, *S. faecalis*, *C. perfringens,* faecal coliforms, heterotrophic and proteolytic bacteria. The samples were obtained from six boreholes and a well situated within a 800-m radius around the Querenc cemetery. The boreholes and the well were situated in karst structures. All samples contained bacteriological pollution (Table 2). However, the authors cited have not excluded a possible impact of septic tanks which were in use in the vicinity of this cemetery. This factor was also highlighted in Brazil (Carvalho & Silva 1997; Braz *et al.* 2000; Matos 2001).

High bacterial counts were also found in porous aquifers at the Luz de Tavira cemetery. The largest differences

Table 1 | Numbers of selected bacteria in groundwater, within cemeteries in a temperate climate zone

Cemeteries	Thermotolerant coliforms[a]	Faecal streptococci[a]	*S. aureus*[a]	*B. cereus*[a]	*C. perfringens*[a]
Danescourt Cemetery in Wolverhampton[b]	1.3×10^3	44	70	9	30
Nine cemeteries and mass graves in Poland[c]	2	3	3	2	2

[a] Max. in CFU·100 ml^{-1}, CFU, colony forming unit.
[b] Trick *et al.* (2001).
[c] Żychowski (2009).

Table 2 | The microbiological contamination of groundwater in three selected cemeteries in Portugal (shortened table, Rodrigues & Pacheco 2003)

		The bacteriological parameters (minimum and maximum)[a] for the borehole samples P (4, 7, 8, 6, 9, 11)				
Boreholes in		**GHM T22[a]**	**TC[b]**	**FC[c]**	**FE[d]**	**CSR[e]**
Querenc	P4	$20–29.6 \times 10^3$	$130–6.9 \times 10^3$	$0–4.4 \times 10^3$	0–6	7–460
	P7	3–133	0–23	0–20	0–4	4–93
	P8	$2–5.0 \times 10^3$	$46–1.9 \times 10^3$	0–395	1–128	$23–4.6 \times 10^3$
Luz de Tavira	P6	27–365	$3–1.9 \times 10^3$	1–121	0–11	$23–1.1 \times 10^3$
	P9	1–293	0–595	0–60	0–7	0–48
Seixas	P11	5–3	4–9	4	0	4

[a] GHM T22, heterotrophic and mesophile bacteria (CFU·100 ml^{-1}) developing at temperatures above 22 °C.
[b] TC, total coliforms (CFU·100 ml^{-1}).
[c] FC, faecal coliforms (CFU·100 ml^{-1}).
[d] FE, faecal streptococci (*S. faecalis*) (CFU·100 ml^{-1}).
[e] CRS, *Clostridium* (MPN·100 ml^{-1}), MPN, most probable number.

between the samples taken from the cemetery and those from the reference site – a distance of c. 300 m – were related to heterotrophic and mesophilic bacteria, total coliforms and the bacteria of the genus *Clostridium* (Table 2).

The highest numbers of all the bacteria studied were found in the Seixas cemetery in Minho. The cemetery is located in a place where sea tides increase the thickness of the filtration layer. The samples from a borehole located in the central part of the cemetery contained decidedly higher quantities of bacteria than those from a borehole situated 290 m away from it.

Rodrigues & Pacheco (2003), on the basis of these studies, suggested that the climate of Portugal, where high precipitation and high air moisture occur in winter, is also a factor boosting bacteriological contamination of groundwater.

Studies in Poland concerned the impact of nine cemeteries and mass graves on the presence of *B. cereus, S. aureus, Staphylococcus* spp., *C. perfringens,* faecal streptococci (*S. faecalis*) and the thermotolerant coliforms in the groundwater (Żychowski 2009). The studies confirmed the differences between the numbers of bacteria in wells situated within the cemeteries or below their sites and their bacteriological background. However, these differences were not large (Table 1). The largest differences occurred in *S. aureus* and faecal streptococci (*S. faecalis*), which were detected in three out of nine burials. Higher numbers of *S. aureus* and thermotolerant coliforms are fostered by sandy substrates, shallow groundwater table levels, contemporary interments and landslides destroying the slopes.

Studies conducted by the World Health Organization (Üçisik & Rushbrook 1988) concerning groundwater under cemeteries revealed the presence of *B. cereus,* faecal streptococci (*S. faecalis*), Micrococcaceae and Entrobacteriaceae. Researchers from Europe (and some from the USA) drew particular attention to the occurrence at such sites of, for example, faecal streptococci (*S. faecalis*), *P. aeruginosa* and *Clostridium* spp. (Rodriguez & Bass 1985; Iserson 1995; Environment Agency UK 2002). It is worth mentioning that the researchers from the USA have not found faecal coliforms at cemeteries within their own country.

Studies in South America

Studies focusing on groundwater quality in cemeteries were mainly developed in Brazil. Bergamo (1954) was the first to draw attention to the impact of cemeteries on the groundwater and surface water contamination in cemeteries and beyond them. During the Fourth Inter-American Congress of Sanitary Engineering in São Paulo, he emphasized the need for geological research and delineation of zones at risk of contamination around cemeteries. Since the early 1980s, these studies have been developed by Professor A. Pacheco at the Centre of Underground Water Research at the University of São Paulo, supported by the Institute of Biomedical Sciences at the same university (Costa *et al.* 2002). His first study covered 22 cemeteries in São Paulo (Pacheco 1986). In this study, he focused on the impact of public cemeteries on the environment and suggested that geological, geotechnical and hydrogeological studies should precede decisions concerning localization of new cemeteries. He also emphasized the need to protect surface and underground water near cemeteries, so that the water could still be used for drinking (Miotto 1990).

Most of the Brazilian studies confirmed the adverse impact of cemeteries on bacteriological contamination of the groundwater. The main results of these studies are briefly presented below.

The Vila Nova Cachoeirinha, Vila Formosa and Areia Branca cemeteries

The studies conducted by Pacheco's team in three Brazilian cemeteries, Vila Formosa and Vila Nova Cachoeirinha in São Paulo and Areia Branca in Santos, confirmed the presence of bacteria in all samples (Pacheco *et al.* 1991). However, the quantities of the bacteria found were not high in any of them.

Samples collected in Vila Nova Cachoeirinha contained mainly proteolytic, heterotrophic, lipolytic bacteria and faecal coliforms (Table 3). When the numbers of these bacteria were high, the samples exuded an insipid smell. It should be mentioned that many of these pathogenic bacteria, e.g., *Pseudomonas* and *Bacillus*, are good indicators of contaminants originating from graves, because they decompose proteins and lipids (Higgins & Burns 1975; Martins *et al.* 1991; Matos 2001).

These authors also found other indicators of contamination, e.g., total coliforms, thermotolerant coliforms, *S. faecalis* and sulphite reducer clostridia. In one case, they even confirmed the presence of *Salmonella*. The thermotolerant coliforms and total coliforms also showed higher numbers in all samples collected from four out of five wells within the Santa Inês Cemetery in Espírito Santo state (Neira *et al.* 2008).

The subsequent studies (Matos & Pacheco 2000, 2002) at the same cemetery (Vila Nova Cachoeirinha) also revealed that samples of groundwater mainly contained heterotrophic and proteolytic bacteria, *C. perfringens,* as well as enteroviruses and adenoviruses (Table 4). These studies demonstrated, however, the low levels of total and faecal coliforms in the groundwater (Matos & Pacheco 2000).

In his voluminous PhD dissertation, Matos (2001) confirmed the high maximum numbers of many bacteria (Table 3). It is worth mentioning that heterotrophic bacteria (being aerobic bacteria) are good indicators for detecting contaminants originating from graves. They are not pathogenic but may pose a hazard to health when high quantities occur.

The groundwater of these three cemeteries (Vila Formosa, Vila Nova Cachoeirinha, Areia Branca) was also investigated by Martins *et al.* (1991). Pacheco's investigations

Table 3 | The numbers of selected bacteria in the groundwater within cemeteries in Brazil, RSA and Portugal

Cemeteries	Heterotrophic bacteria[a]	Proteolytic bacteria[b]	*Clostridium perfringens*[b]	Total coliforms[b]	Faecal coliforms[b]
Vila Nova Cachoeirinha, Brazil[c]	53×10^3	9×10^3	27	1.6×10^3	7
Vila Nova Cachoeirinha, Brazil[d]	40×10^3	16×10^3	2.2×10^3	1.6×10^3	1.6×10^3
Várzea, Recife, Brazil[e]	$\approx 172 \times 10^3$	$\geq 2.4 \times 10^3$	>23	–	–
Santo Amaro, Campo Grande, Brazil[f]	up to 4.4×10^4	up to 1.1×10^5	up to 200	3.6×10^1	–
Ditengteng, Tshwane, South Africa[g]	5×10^3	–	–	9×10^3	up to 6.1×10^3
Western Cape, South Africa[h]	5.9×10^6	–	–	–	77.4×10^3
Seixas w Minho, Portugal[i]	4.8×10^3 ([j])	–	4.6×10^3	3.9×10^3	4.4×10^3

[a] CFU·100 ml^{-1}, CFU, colony forming unit.
[b] MPN·100 ml^{-1}, MPN, most probable number.
[c] Pacheco *et al.* (1991).
[d] Matos (2001).
[e] Espindula (2004).
[f] Abrão (2007).
[g] Tumagole (2006).
[h] Engelbrecht (1993).
[i] Rodrigues & Pacheco (2003), borehole P10.
[j] heterotrophic and mesophilic bacteria.

Table 4 | The quantities of selected bacteria in underground water in several of the 20 piezometers installed in the de Vila Nova Cachoeirinha cemetery in São Paulo, Brazil (shortened table, Matos & Pacheco 2002)

Number of boreholes	Heterotrophic bacteria[a] (from..to..)	Total coliforms[b] (from..to..)	Faecal coliforms[b] (from..to..)	Proteolytic bacteria[b] (from..to..)	Clostridium sulfito redutores[b] (from..to..)
P1	120 to 110×10^4	< 2 to 10	<2 to 10	< 2 to 300	< 2 to 1.6×10^3
P5	90×10^2 to 77×10^3	23 to170	2 to 30	22 to 16×10^3	130 to $\geq 1.6 \times 10^3$
P7	54×10^3 to 40×10^5	< 2 to $\geq 1.6 \times 10^3$	<2 to $\geq 1.6 \times 10^3$	10 to $\geq 16 \times 10^3$	< 2 to $\geq 1.6 \times 10^3$
P9	180×10^2 to 170×10^3	< 2 to $\geq 1.6 \times 10^3$	<2 to 300	< 2 to $\geq 1.6 \times 10^3$	13 to 1.3×10^3
P13	32×10^3 to 86×10^3	< 2 to 4	<2 to 2	10 to 500	23 to 1.3×10^3
P15	85×10^3 to 29×10^3	< 2	<2	20 to 500	500 to 2.2×10^3
P20	95×10^2 to 52×10^3	2 to 23	<2	8 to 170	8 to 170

[a] CFU·100 ml^{-1}, CFU, colony forming unit.
[b] MPN·100 ml^{-1}, MPN, most probable number.

(Pacheco *et al.* 1991) were performed at almost the same time as those of Martins *et al.* (1991). Martins' team analysed 67 groundwater samples. Most of the samples contained higher quantities of *S. faecalis* and sulphite reducer clostridia compared with the faecal coliforms (Table 5). The presence of coliphages was not confirmed (Martins *et al.* 1991). The authors suggested that *S. faecalis* and sulphite reducer clostridia content are more appropriate indicators for evaluation of the sanitary conditions of the cemetery groundwater. In this study the *Salmonella* spp. were detected in one of the 44 analysed samples. However, the occurrence of these dangerous bacteria, with a maximum of 3,000 CFU·100 ml^{-1} (determined by the membrane filter method), was confirmed by Final (2007) in two cemeteries: São Goncalo and Parque Bom Jesus in the Cuiabá region of Mato Grosso state.

Table 5 | The maximum values of bacteriological indicators found in samples collected in three Brazilian cemeteries (Martins *et al.* 1991), simplified table

	Cemeteries		
Bacteria	Areia Branca, Santos	Vila Formosa, São Paulo	Vila Nova Cachoeirinha, São Paulo
Total coliforms[a]	1.6×10^3	1.6×10^3	1.6×10^3
Faecal coliforms[a]	1.6×10^3	3.0×10^2	7
S. faecalis[a]	1.6×10^3	1.6×10^3	1.6×10^3
Sulphite reducer clostridia[a]	1.6×10^3	2.4×10^2	27
Proteolytic[a]	1.6×10^3	1.6×10^3	9.0×10^3
Heterotrophic[b]	8.1×10^6	7.1×10^5	5.3×10^4
Lipolytic[b]	1.2×10^6	1.5×10^3	3.6×10^4

[a] MPN·100 ml^{-1}, MPN, most probable number.
[b] CFU·100 ml^{-1}, CFU, colony forming unit.

Among the cemeteries (Vila Nova Cachoeirinha, Vila Formosa, Areia Branca) the worst quality of groundwater was recorded at the Areia Branca cemetery in Santos (Table 5).

According to Pacheco *et al.* (1991), diversity in the numbers of bacteria in cemeteries' groundwater is associated mainly with varying lithological conditions as well as the depth of the groundwater table. Similar conclusions were formulated by Martins *et al.* (1991) and Matos (2001). The poor quality of the groundwater at the Areia Branca cemetery in Santos is associated with the permeable sandy formations (Quaternary age marine sediments) and shallow groundwater table – c. 2.2 m below the terrain surface (Martins *et al.* 1991). The environmental settings of the remaining two cemeteries in São Paulo are slightly different. The groundwater table is significantly deeper and reaches, on average, 12.0 m below the terrain surface (Bastianon *et al.* 2000). The substrate of the Vila Formosa cemetery is mainly composed of alternating layers of clays and sandy clays of Tertiary age sediments (Migliorini 1994). In turn, in the Vila Nova Cachoeirinha cemetery, the substrate is mainly composed of sandy sediments containing clayey layers. These clayey layers are acidic and contain few organic substances. As a result, they are not very active in terms of ion exchange (Matos *et al.* 2002). The authors even emphasized hydraulic conductivity of the substrate. Clayey substrates are less permeable to a cemetery's effluents. In this way they limit a cemetery's impact on the bacteriological contamination of the groundwater. The large influence of this factor was also confirmed in the studies at the Vila Rezende cemetery in Piracicaba, where hydraulic conductivity amounted to 6.5×10^{-7} cm·s^{-1} (Silva *et al.* 2011).

It should be noted that those investigations contributed to the development of a method enabling evaluation of susceptibility of the groundwater to bacteriological contamination. The GOD method (an abbreviation of Groundwater hydraulic confinement; Overlaying strata; Depth to groundwater table) suggested by Foster *et al.* (2006) was used to estimate the susceptibility to contamination of groundwater at four cemeteries in Santa Maria in the state of Rio Grande do Sul (Kemerich *et al.* 2010). The results revealed that the method may be very useful for the evaluation of the bacteriological contamination hazard in cemeteries and their vicinity.

Finally, it is worth presenting an investigation concerning the migration of bacteria, performed by Matos (2001) in the Vila Nova Cachoeirinha cemetery. The studies revealed that bacteria may migrate over a distance of several metres beyond the cemetery. The number of bacteria decreased as the distance from the interments increased. Viruses turned out to be more mobile than bacteria, moving tens of metres. The viruses were also transported at least 3.2 m through the unsaturated layer and reached the groundwater layer. These investigations also revealed that the highest contamination occurred at those places where the graves were close to the water table, the graves were not older than one year and the graves were situated in the low-lying parts of the cemetery.

The effect of shallow groundwater table on the high bacteria content, mentioned by Pacheco *et al.* (1991), Martins *et al.* (1991) and Matos (2001), was also confirmed in research conducted in two cemeteries: da Paz and da Saudade in Belo Horizonte in the state of Minas Gerais by Costa *et al.* (2002) and in two necropolises (São Gonçalo and Parque Bom Jesus) in the Cuiabá region of the Mato Grosso state (Final 2007). In all of these four cemeteries the groundwater quality was unsatisfactory. No presence of *E. coli* was found in these cemeteries. In general, however, in all these four cemeteries, the quality of groundwater was unsatisfactory. Of particular concern is the maximum number of thermotolerant coliforms – 2.4×10^6 CFU·100 ml^{-1} in a sample collected from a low-lying place. It is worth emphasizing that thermotolerant coliforms are rarely recorded near places of burial (Martins *et al.* 1991). This fact results from their shorter survival time in the soil and groundwater compared with other bacteria of the coli group.

The Itaquera cemetery

Studies at the Itaquera cemetery (Silva *et al.* 2008) revealed the presence of total coliforms and bacteria classified as *Shigella* and *Klebsiella* spp., capable of causing diarrhoea. The high level of groundwater contamination was explained by: (1) location on a steep slope (40%); (2) sandy-clayey bedrocks with suspended aquifer, covered by an impermeable layer of red lateritic loam; (3) lack of a sewage system at the cemetery; (4) lack of management plans at the cemetery; (5) leaking tombs and graves; (6) faults in grave construction; (7) faults in the interment procedures; and (8) lack of appropriate collection and utilization of the solid waste from the cemetery. Such conditions were conducive to ground erosion and landsliding that even predisposed groundwater contamination. In addition, a distance of less than 50 m to the nearest building estate also had an adverse impact on the quality of water. All these factors contributed to the conclusion that the location of the Itaquera cemetery in São Paulo was unfavourable.

The São José cemetery

The elevated numbers of bacteria: heterotrophic – up to 300×10^2 CFU·100 ml^{-1}, total and faecal coliforms – up to 8×10^3 MPN·100 ml^{-1} (MPN, most probable number), and faecal streptococci (*S. faecalis*) – up to 235 CFU·100 ml^{-1}, were also confirmed at the São José cemetery in Belém in Pará state (Braz *et al.* 2000). The faecal coliforms and faecal streptococci were not found in a control artesian well. However, significant contamination of the groundwater by faecal and total coliforms (up to 13×10^3 MPN·100 ml^{-1}) occurred in the well below the cemetery, as well as in a stream flowing c. 100 m from the cemetery boundary. This small stream acts as a water-collector for the surface water from the cemetery. Some contamination may even come from neighbouring households (Braz *et al.* 2000). High groundwater contamination was also boosted by permeable, vulnerable-to-pollutants Tertiary age outcrops made of fine- and medium-grained sands.

The Várzea cemetery

In the Várzea cemetery in Recife, Espindula & Santos (2004) collected samples from three piezometers and five wells. They were located within and beyond the cemetery, at distances ranging from 6 to 110 m from the cemetery boundary. He found *P. aeruginosa* in all samples, with numbers $\geq$1,600 MPN·100 ml^{-1}. Remarkable quantities of *P. aeruginosa* were confirmed by other researchers in individual wells (Martins *et al.* 1991; Vasconcelos *et al.* 2006). It should be emphasized, that this bacterium inhibits the growth of total coliforms (CETESB 1996; Guilherme & Silva 1998; Almeida *et al.* 2006). Therefore, these bacteria were not found (Table 3).

In this cemetery, water from the piezometers also contained heterotrophic and proteolytic bacteria, as well as sulphite reducer clostridia (Table 3). High numbers of these bacteria, particularly the proteolytic types, provided the evidence that higher quantities of microorganisms appear, especially in the piezometers situated near the graves less than one year old (Almeida *et al.* 2006).

In the Várzea necropolis, the clastic substrates, where the graves were located, are up to 8 m in thickness. Unfortunately, these sediments have high permeability due to their lithology, composed to a depth of 3 m of sands, silts and loams; from 3 m to 6 m of poorly graded gravels; and below 6 m of sands. Moreover, the groundwater table fluctuates in the range of 2.9–9.5 m below terrain surface (Espindula & Santos 2004; Almeida *et al.* 2006). The contamination is facilitated by mostly shallow graves with coffins placed directly into the ground at depths ranging from 0.6 to 0.8 m (Santos & Espindula 2005). At the time when this necropolis was studied, there were 3,519 graves on an area of 2.2 ha.

The Santo Amaro cemetery

Studies at the Santo Amaro cemetery in Campo Grande in Mato Grosso do Sul state (Abrão 2007) revealed higher numbers of heterotrophic and proteolytic bacteria. At this site, *C. perfringens* and total coliforms occurred only in two wells (Table 3). In one well higher numbers of *S. faecalis* and *E. coli* were also found (Table 6). These wells were situated in the middle and lower parts of the slope. According to a cautious opinion expressed by Abrão (2007), such a contamination of the groundwater could be linked to the decomposition of corpses during the period of the studies. At that time, there were 24,000 graves on an area of 27.3 ha. The contamination could also be increased by shallow graves with depths ranging from 1.70 to 2.50 m. The corpses were also buried sporadically on three levels. According to Abrão (2007), the groundwater level is shallow there, ranging between 5.65 and 12.50 m. This diversity results from the cemetery being situated on an upland slope of a basaltic cuesta, descending gently from an elevation of 597.50 to 585.77 m

Table 6 | The numbers of selected bacteria found in groundwater within cemeteries in Australia and Brazil

Cemeteries	Total coliforms[a]	*S. faecalis*[b]	*P. aeruginosa*[b]	*E. coli*[b]
Botany in Sydney[c]	to 5	to 2	to 2	–
Guildford in Perth[d]	to 8	–	to 11	–
Necropolis in Melbourne[d]	2.4×10^3–3×10^3	to 22	–	10
Cheltenham in Adelaide[e]	2×10^3	–	to 40	–
Woronora in Sydney[d]	to 500	0	to 4	to 2
Santo Amaro in Campo Grande[f]	–	9.1×10^1	–	3.6×10^1

[a] MPN·100 ml^{-1}, MPN, most probable number.
[b] CFU·100 ml^{-1}, CFU, colony forming unit.
[c] Dent 2005.
[d] Dent & Knight 1998.
[e] Knight & Dent 1998.
[f] Abrão 2007; [c,d,e] in Australia; [f] in Brazil.

above sea level. The infiltration of relatively high rainfall, c. 1,500 mm per year in a tropical climate, is facilitated by the considerable proportion of sand in the substrate (44% sand, 31% loam and 25% silt). This is indicated by a high permeability coefficient which ranges from 5 to 10 $\text{cm} \cdot \text{s}^{-1}$.

The studies presented so far emphasized the adverse impact of cemeteries on the groundwater quality in their surroundings. According to Silva, L. M. (2000) 75% of 600 cemeteries in Brazil pollute the environment. However, some Brazilian research has revealed that the influence of cemeteries on groundwater contamination is less noticeable. This fact was confirmed in the studies conducted on a newly founded but closed municipal cemetery in Parque Bom Jardim on Estrada Jatobá street in Fortaleza in Ceará state (Sousa *et al.* 2008). In contrast to the previously discussed cemeteries, this cemetery was established on clays and silts. In such environmental settings, average velocity of the groundwater flow (calculated on the basis of monitoring the contamination in nine piezometers), reached 0.27 m per day. The study revealed that the zone of groundwater contamination around the border of the cemetery did not exceeded 13.5 m and time of migration took up to 50 days (Sousa *et al.* 2008). It is worth remembering that in fine-grained sediments the biological contaminants may migrate up to 30 m (Romero 1970).

The influence of limited infiltration in clayey sediments on the biological contamination of the groundwater was also confirmed by Oliveira *et al.* (2002). They noted an increasing biodegradation of organic matter and elimination of bacteria in substrate downward of the vertical profile. This phenomenon occurred in the moist tropical climate in the Domini Max II cemetery, in the Belém region in Pará state.

No negative impact on the groundwater was demonstrated in the study carried out by Mello *et al.* (1995) on a contemporary cemetery at da Paz in São Paulo. The study did not confirm the presence of faecal coliforms, faecal streptococci (*S. faecalis*), sulphite reducer clostridia, coliphages and *Salmonella* in the groundwater collected from two wells near the graves. There were only small numbers of heterotrophic bacteria and total coliforms.

The preliminary studies conducted at the Santana cemetery, on the Ilha de Maré island in Salvador in the state of Bahia (Leite 2009), confirmed that groundwater was polluted by total coliforms and thermotolerant coliforms (c. 200 $\text{CFU} \cdot 100\ \text{ml}^{-1}$). However, the author concluded that the contamination did not exceed the norms (Leite 2009).

Worthy of mention is that some Brazilian researchers have doubts concerning the negative impact of cemeteries on groundwater quality in the vicinity of these areas. According to Espindula (2004), the increased quantities of total coliforms and the presence of faecal coliforms or thermotolerant coliforms in two household wells near the Várzea cemetery in Recife, can be also connected to other factors, e.g., leaky sewage systems. Similar doubts have also been raised by other researchers (Mello *et al.* 1995; Carvalho & Silva 1997; Braz *et al.* 2000; Matos 2001; Almeida *et al.* 2006; Sousa *et al.* 2008; Leite 2009). Almeida *et al.* (2006) found relatively low levels of contamination in a household well near the cemetery compared with a more distant well. In their opinion, this finding resulted from other factors, including additional sources of pollution, such as the lack of sewage systems or their leakages, the conservation and cleanliness of the well, the type of aquifer in use, and the rainfall amounts.

These arguments may suggest that investigation focusing on groundwater contamination by bacteria and viruses must take into account additional factors not directly related to the cemeteries, e.g., spatial distribution of the sewerage system and its condition, etc.

Studies in Africa

Studies carried out in South Africa revealed that the localization of many cemeteries was incorrect. Significant microbiological contamination of groundwater was found by Engelbrecht (1993) in a municipal cemetery in the Western Cape Province (Table 3). He evaluated the water quality on the basis of 20 wells situated within the cemetery, one well located at 50-m distance, and a reference (control site) municipal well 500 m away from the cemetery (Engelbrecht 1993). The wells, set in sands, showed high quantities of *E. coli* ($57.4 \times 10^3\ \text{CFU} \cdot 100\ \text{ml}^{-1}$), *S. faecalis* ($205.0 \times 10^3\ \text{CFU} \cdot 100\ \text{ml}^{-1}$), *S. aureus* ($5.4 \times 10^3\ \text{CFU} \cdot 100\ \text{ml}^{-1}$), heterotrophic bacteria and faecal coliforms (Table 3).

High groundwater contamination was also diagnosed at Ditengteng cemetery in Tshwane (Tumagole 2006). In samples collected from several wells situated in their vicinity, high levels of several microbiological parameters (e.g., total coliforms and faecal coliforms and a number of heterotrophic bacteria) were found (Table 3). Moreover, Tumagole (2006) found *E. coli* in two samples. These bacteria occurred in shallow groundwater in an unconfined sandy aquifer and in the coastal zone. The level of the groundwater increases during the rainy season in Tshwane. As a consequence, the contamination of the environment by microorganisms originating from the cemetery takes place (Tumagole 2006).

Total and faecal coliforms were also found in groundwater in the urban Granaville cemetery in Harare, Zimbabwe (Tumagole 2006). These results were obtained in seven piezometers situated at the cemetery itself, and downslope, and compared to a control site.

African researchers are of the opinion that the biological contamination of groundwater at the African cemeteries are associated with: (1) the number of burials; (2) the physical, chemical and biological properties of the natural environment; (3) fluctuations of the groundwater table; (4) circulation of the groundwater in the substrate; and (5) the ability to create binding between decomposition products and the substrate, and organic matter (Wright 1999).

Studies in Australia

A smaller impact of cemeteries on the groundwater contamination was found in Australia. Two series of studies by Dent (1995, 2005) carried out at the Botany cemetery in Sydney revealed low levels of bacteriological contamination. The groundwater was polluted by total coliforms, *S. faecalis*, faecal coliforms and *P. aeruginosa* (Table 6). These microorganisms were found in piezometers situated along the line of water runoff, particularly below new graves, in four out of 11 boreholes (Dent 2005).

Dent (2000a) also reported increased quantities of microorganisms: faecal coliforms (*E. coli*), faecal streptococci (*S. faecalis*) and *P. aeruginosa* in the vicinity of graves at the Botany cemetery in Sydney, and at the Guildford cemetery in Perth (Table 6). The number of bacteria decreased rapidly with a growing distance from the graves. According to Knight & Dent (1998) and Dent (2000a) the migration of microorganisms in these cemeteries is hampered by the lithology of substrate. In Sydney, the substrate is composed of sandy clays and a clayey mantle of sandstone (Knight & Dent 1998). The cemetery in Perth is located on shallow marine sediments of Holocene age, composed of clayey and silty sands, and fine sands (Dent 2000a). A considerable reduction of the decomposition products may also result from the activities of naturally occurring microorganisms not associated with interments, e.g., with iron bacteria, and also sulphur bacteria of the genus *Thiobacillus* (Knight & Dent 1998).

The importance of hydrogeological conditions was also confirmed by studies carried out in the Cheltenham cemetery in Adelaide. This cemetery is above an aquifer of the Adelaide Plain (River Torrens Fan of the Lower Outwash Plain), Pooraka Formation, with a phreatic surface between 4 and 4.7 m below the terrain surface. The substrate is composed of silty and sandy clays, silty clayey sands and minor silty sandy lenses, the latter probably representing channel fills. In this case, the depth of the groundwater table (4.0–4.7 m) was considered a factor that restricted groundwater contamination (Knight & Dent 1998). In spite of these good hydrogeological conditions, a pathogenic bacterium *P. aeruginosa* was found in the groundwater. Moreover, higher quantities of total coliforms were found (Table 6).

The unconsolidated but firm clays up to 10–12 m thick that overlie sandy silts and silty sands of the Brighton Group formations at the Necropolis cemetery in Melbourne also did not appeared to constitute an efficient barrier (Dent & Knight 1998). Even though the aquifer was sampled at a depth ranging from 14 to 28 m, the researchers found the presence of several groups of bacteria: total coliforms, *S. faecalis* and faecal coliforms (Table 6). Their numbers varied considerably over time. Additionally, in three wells situated at the cemetery, the bacteria classified as total coliforms were found in quantities ranging from 2.4×10^3 to 3×10^3 $\mathrm{CFU \cdot 100\ ml^{-1}}$. The numbers of *E. coli* and *S. faecalis* were significantly higher (Table 6). Their numbers decreased rapidly with distance from the cemetery. Dent & Knight (1998) regarded that the presence of all decomposition products in the groundwater resulted from water seeping into the wells at a depth of 2.5–5.5 m below the terrain surface. Some contamination might come from the decomposition of coffins and embalming substances.

The studies carried out by Dent in Australia (2000b, 2004) revealed low levels of bacteriological groundwater pollution in a moderate climate condition. Irrespective of the bedrock settings, most of the microorganisms did not migrate deeper than 3 m (Bitton & Harvey 1992; Dent 2004). Only during long-lasting rainfall periods did they migrate a distance further than 100 m (Kieft & Brockman 2001).

The increased numbers of bacteria are usually related to: (1) inappropriate localization of cemetery (e.g., adverse hydrogeological conditions); (2) inappropriate management practices; and (3) occurrence of natural disasters (e.g., storms, floods or landslides). According to Dent (2004), (1) dry sands, (2) anaerobic conditions, (3) high temperatures (>40 °C), (4) direct insolation, (5) low pH and (6) presence of other bacteria species create preferable conditions for a decrease in the numbers of bacteria and viruses.

CONCLUSIONS

Summary of contamination characteristics

In a moderate climate condition, a relatively low impact of cemeteries on groundwater pollution by bacteria and viruses was observed. Higher numbers of bacteria are primarily associated with long-lasting rainfall periods. This regularity was confirmed by an increase in the numbers of thermotolerant coliforms, faecal streptococci and *S. aureus* at a contemporary cemetery in Wolverhampton, and in nine cemeteries and mass graves in Poland (Table 1).

Low groundwater contamination was also observed in the Guilford cemetery in Perth, located in Mediterranean climate conditions (870 mm annual rainfall) and in the Woronora and Botany cemeteries in Sydney (Table 6), located in a subtropical climate (1,100 mm annual rainfall). Slightly higher numbers of *S. faecalis* and *E. coli*, found in the Cheltenham cemetery in Adelaide (Mediterranean climate – 560 mm annual rainfall), could be a result of fluctuation of saline groundwater (Knight & Dent 1998).

Significantly higher biological groundwater contamination was recorded in warmer and moister climates (Tables 3, 4 and 6). The Santo Amaro cemetery in Campo Grande (Table 6), located in a tropical climate (annual rainfall of 1,500 mm) with a rainy summer and dry winter is one example.

High numbers of bacteria occurred in groundwater in cemeteries in Brazil, the Republic of South Africa and Portugal (Tables 3–6). In the vicinity of necropolises located in the southern part of Africa, the increases were recorded with respect to all microbiological indicators (Table 3), namely, total coliforms, faecal coliforms, heterotrophic bacteria, faecal streptococci, *E. coli* and *S. aureus* (Fisher & Croukamp 1993; Engelbrecht 1998; Tumagole 2006). One of the highest contamination levels was diagnosed in the Western Cape cemetery in the Republic of South Africa, situated in loose sands (Engelbrecht 1993). Such a substrate is particularly conducive to contamination (Martins *et al.* 1991; Braz *et al.* 2000; Rodrigues & Pacheco 2003; Almeida *et al.* 2006; Żychowski 2009; Silva *et al.* 2011).

Many authors noted the occurrence of *P. aeruginosa* at the cemeteries in Brazil (Pacheco *et al.* 1991; Espindula 2004) and in Australia (Knight & Dent 1998; Dent 1998; 2005; Dent & Knight 1998).

Thermotolerant coliforms were often absent from the vicinity of interments (Martins *et al.* 1991). This results from their shorter survival time in the soil and groundwater, compared with other bacteria from the coli group. These bacteria were most often reported in samples taken from low-lying places at contemporary cemeteries in Brazil (Final 2007; Neira *et al.* 2008). They were also reported during rainfall periods at cemeteries in England (Trick *et al.* 2001).

The largest quantities of *E. coli* (Abrão 2007) were noted in Brazil. Small amounts were found in Australia, in the Necropolis cemetery in Melbourne, in the Woronora and Botany cemeteries in Sydney and in the Guildford cemetery in Perth (Table 6).

Salmonella spp. bacteria were found in cemeteries in Brazil (Pacheco *et al.* 1991; Martins *et al.* 1991; Final 2007); however, they were not detected in groundwater in cemeteries in Poland, England, South Africa and Australia.

The research approaches used to evaluate the bacteriological contamination of the groundwater by cemeteries differ slightly in the regions studied. This fact hampers comparison of the results obtained. For example, in the World Health Organization report (Üçisik & Rushbrook 1988), attention has been drawn to the presence of *B. cereus,* faecal streptococci (*S. faecalis*), Micrococcaceae and Enterobacteriaceae in groundwater under cemeteries. In turn, the indicators of water contamination universally used in Brazil include the bacteria from the group of total coliforms (*Citrobacter, Klebsiella* and *Enterobacter*), faecal coliforms, thermotolerant coliforms (*E. coli*), *Streptococcus* (*S. faecalis*) and *Clostridium* (*C. perfringens)* (CETESB 1996). Braz *et al.* (2000) have also noted *Salmonella*, lipolytic and proteolytic bacteria, whereas Matos & Pacheco (2000) identified heterotrophic bacteria. Few researchers have paid attention to viruses, e.g., coliphage 30, coliphage T134 and coliphage T4 (Final 2007). In Australia, the indicators of microbiological contamination include faecal coliforms, *P. aeruginosa*, as well as *E. coli* and faecal *Streptococcus* (Dent 2000b).

The role of environmental factors – summary

The review revealed the large influence of climatic conditions on the bacteriological contamination of the groundwater, at the regional scale. Most researchers express the opinion that warmer and moister climate is the principal factor in significant contamination of the environment – including the groundwater (Silva, J. A. F. 2000; Silva, L. M. 2000). They observed that during long-lasting periods of rainfall, microorganisms can be transported even over a distance exceeding 100 m. The Brazilian researchers are of the opinion that this negative impact could be contained through proper burial site management and the correct placement of cemeteries (Silva, J. A. F. 2000; Silva, L. M. 2000). Therefore, in many reviewed studies the role of other environmental factors was emphasized. These factors influence the groundwater pollution, especially at the local scale. Many researchers emphasized the role of geological settings and lithology of substrate, the relief conditions as well as the depth of the groundwater table and its fluctuation (Gray *et al.* 1974; Pacheco *et al.* 1991; Martins *et al.* 1991; Engelbrecht 1993; Rodrigues & Pacheco 2003; Almeida *et al.* 2006; Żychowski 2008). These factors were often responsible for spatial diversity of the groundwater contamination within a cemetery and its vicinity (Pacheco 1986; Antunes *et al.* 1998; Dent 1998; Morgan 2004). It is particularly significant for the cemeteries situated on slopes.

Geological settings and lithology of substrate affect infiltration rate, sorption capacity and groundwater circulation. In this way, these factors influence migration of the microorganisms – both in time and distance (Pacheco 1986; Silva 1994; Dent 2004). In this context, few studies revealed some kind of regularity. As the distance from the places of interment increases, the quantity of microorganisms rapidly decreases (Mello *et al.* 1995; Knight & Dent 1998; Dent & Knight 1998; Oliveira *et al.* 2002). This regularity was observed mainly in sandy clays and clayey grounds, and was explained by limited infiltration. The role of the substrate sorption capacity was emphasized by Matos (2001), Dent *et al.* (2004) and Josias & Harris (2004). The higher the sorption capacity (e.g., in clays) the more viruses were retained. The fine-grained substrate may also retain larger organisms such as bacteria during the filtration process. In this context, silty substrates more effectively retain bacteria contrary to corase sand (Matos 2001).

Pathogens quickly migrate to the groundwater when the water table is shallow, e.g., in periods of intensive precipitation (Pedley & Guy 1996; Josias & Harris 2004). The pathogens die faster in the aeration zone than in the saturation zone and their transport in the saturation zone is slower than the groundwater flow (Gray *et al.* 1974). Many reviewed studies revealed some kind of regularity, namely, the more shallow the groundwater table the more bacteria occur in the water.

Many studies confirmed higher numbers of microorganisms in the vicinity of graves less than a year old (Pacheco 1986; Martins *et al.* 1991; Matos 2001; Migliorini 2002; Morgan 2004; Almeida *et al.* 2006) as well as near those which were placed close to the groundwater table (Dent & Knight 1998; Matos 2001; Costa *et al.* 2002; Almeida *et al.* 2006; Abrão 2007; Final 2007; Żychowski 2008).

According to Australian researchers, the groundwater contamination could also be predisposed by: (1) the lack of sewage systems at cemeteries; (2) errors made in grave construction; (3) faults in preparation and interment of corpses; (4) leaky tombs, cracks in graves; and, finally, (5) the lack of appropriate collection and utilization of solid waste in cemeteries (Silva *et al.* 2008). The researchers in South Africa see a dependence of the impact of cemeteries on groundwater contamination with one or more of the following factors: (1) the number of interments; (2) the physical, chemical and biological properties of natural habitats; (3) fluctuation in groundwater tables; (4) circulation of water in the substrate; and (5) the processes of binding between the decomposition products and the substrate, soil and organic matter (Wright 1999).

A number of cemeteries are parts of urban areas (Hirata & Suhogusoff 2004). In the context of studies presented in this review, evaluation of the cemetery impact on the groundwater contamination must be well balanced. It should take into account the influence of other factors natural and anthropogenic – e.g., the lack of sewage systems or their leaking, conservation and cleanliness of wells (Mello *et al*. 1995; Braz *et al*. 2000; Espindula 2004; Almeida *et al*. 2006; Sousa *et al*. 2008; Leite 2009).

Recommendations

The reviewed studies allow development of some recommendations intended to protect the health of employees of funeral homes and the residents living in the vicinity of cemeteries, as well as preserve the natural environment for future generations. Therefore, this review is summarized by the following list of recommendations:

1. Location of new cemeteries, and expansion and management of existing cemeteries should be preceded by obtaining appropriate environmental licence (e.g., Gambin *et al.* 2008). In this context the legal regulations are required. Older cemeteries should be successively changed and adapted to the new requirements.
2. Cemeteries should be located on gentle slopes. Higher slope gradients create favourable conditions for surface flow, flooding of graves, leaching and migration of decomposition products.
3. Cemeteries should be located on bedrocks where:
   - (a) the clay mineral content ranges between 20 and 40%;
   - (b) the bottom of the grave is at least 1.5 m above the maximum groundwater level. When the substrate has a permeability ranging from 10^{-5} to 10^{-7} cm·s^{-1} (or higher), this distance should be higher.
4. Cemeteries should not be located in areas where:
   - (a) the groundwater level is shallow;
   - (b) seasonal or ephemeral floods occur;
   - (c) the substrate is very permeable (e.g., sands and gravels, fractured rocks, karst structures);
   - (d) the substrate has low permeability (e.g., clays and loams) and anaerobic conditions create favourable conditions for adipocere.
5. Cemeteries and the neighbouring areas should have stormwater drainage systems.
6. Cemeteries should be surrounded by buffer zones composed of trees with deep root systems.
7. The groundwater in cemeteries should be monitored both in terms of biological contamination and the depth of its table level.
8. People responsible for management processes in a cemetery should:
   - (a) develop a model for storing special waste, i.e., human corpses;
   - (b) establish recommendations concerning appropriate treatment of remains and leachates;
   - (c) establish recommendations in order to prevent migration of decomposition products into the substrate;
   - (d) establish recommendations for preparation of interments; those should focus on: construction of coffins, the manner of preparing corpses (including embalming), conservation of coffins, clothing items placed in coffins;
   - (e) establish recommendations concerning maintenance of gravestones and their surrounding areas (including their conservation practices); these solutions should be authorised by the relevant environmental agencies.
9. People directly involved in the interment of victims of catastrophic events, namely soldiers, paramedics and other people exposed to infectious bacteria should be equipped properly.
10. Employees of funeral homes should use appropriate boots, gloves and face masks during work related to burials or exhumations. They should wash their hands and take a shower before leaving the cemetery.

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