Impacts on the Groundwater Quality Within a Cemetery Area in Southeast Brazil

A.G. Fineza, E.A.G. Marques, R.K.X. Bastos, L.S. Betim

Abstract. This article presents the results of a case study carried out in the cemetery of Tabuleiro, state of Minas Gerais, Brazil, from August 2007 to March 2008. Five sampling wells were drilled within the cemetery area, and water samples analyzed for pH, conductivity, nitrogen ammoniacal nitrogen, nitrate, total phosphorus, sodium, potassium, calcium, manganese, BOD, COD, total coliforms and *E. coli*. The results demonstrated that the groundwater is subjected to contamination from burials leakage and the most evident impacts have been observed in the sampling well located downstream of the cemetery site.

Keywords: cemetery, contamination, flooding plains, groundwater, environmental impacts.

1. Introduction

Frequently, cemeteries in Brazil have been constructed close to settlements because of religious and culture circumstances or lack of land availability in populated areas. Also, several have been sited without proper geological and hydrological assessments, therefore posing environmental impacts and public health risks (Üçisik & Rushbrook, 1998).

Typical human bodies are composed of water (64%), proteins (20%), fat (10%), mineral salts (5%), and carbohydrates (1%). The human body of a 70 kg adult male contains approximately: 16 000 g carbon, 7 000 g hydrogen, 1800 g nitrogen, 1 100 g calcium, 500 g phosphorous, 140 g sulfur, 140 g potassium, 100 g sodium, 95 g chlorine, 19 g magnesium, 4.2 g iron, and water 70-74% by weight. The elemental composition of females is between two thirds and three quarters of that for males (Üçisik & Rushbrook, 1998; Environmental Agency, 2004).

The progression of human decomposition has been described as taking place through the stages of autolysis, putrefaction and diagenesis. The process of autolysis (or self-digestion) begins rapidly after death has occurred, causing cells to rupture and releasing nutrient-rich fluids. The following process, putrefaction, is the destruction of the soft tissues of the body by the action of microorganisms (bacteria, fungi and protozoa) and results in the catabolism of tissue into gases, liquids and simple molecules. At this point in the decay cycle electrolytes are rapidly leaching out of the body. Saponification or adipocere formation (the formation of soap from fat under high pH conditions) typically occurs after the onset of putrefaction in warm, moist, environments and is seen as deposits of a yellowish white, greasy, wax-like substance. Finally, diagenesis is a natural process that serves to alter the proportions of organic (collagen) and inorganic components (hydroxyapatite, calcium, magnesium) of bone exposed to environmental conditions, especially moisture. This is accomplished by the exchange of natural bone constituents, deposition in voids or defects, adsorption onto the bone surface and leaching from the bone. This complex pathway leads to the formation of various gases (hydrogen sulfide, carbon dioxide, methane, ammonia, sulfur dioxide and hydrogen), and the release of by-products rich in fatty acids, phenolic compounds and glycerols, indole, 3-methylindole (skatole), and toxic diamines (cadaverine and putrescine) (Vass *et al.*, 1992; Vass, 2001).

A wide variety of microorganisms are involved in the decompositional process of human corpses. Strict aerobic organisms play a role only in the very early stages of putrefaction and are rapidly replaced by anaerobic organisms which constitute the vast majority of organisms found in human tissues. Although the intestine hosts a large array of microorganisms, only relatively few groups have been implicated as major colonizers of human corpses during putrefaction, such as *Clostridium spp*., *Streptococci* and *Enterobacteriaceae*. In addition to these, putrefactive bacteria such as micrococci, coliforms, diptheroids. *Bacillus* spp., *Staphylococcus* spp. and *Pseudomonas aeruginosa* can also be found (Üçisik & Rushbrook, 1998; Vass, 2001). Thus, typical microorganisms known to be responsible for waterborne diseases can be present in cemeteries seepage, including micrococcaceae, streptococci, bacillus, enterobacteria (*e.g. Salmonella*), as well as viruses. Besides bacteria, other microorganisms, like saprophyte fungi and

A.G. Fineza, Civil Engineer, D.Sc. Student, Departamento Engenharia Civil, Universidade Federal de Viçosa, Campus Universitário, Viçosa, MG, Brazil. e-mail: adonaifineza@yahoo.com.br.
E.A.G. Marques, Geologist, Associate Professor, D.Sc., Departamento Engenharia Civil, Universidade Federal de Viçosa, Campus Universitário, Viçosa, MG, Brazi. e-mail: emarques@ufv.br, eagmarques1965@gmail.com.
R.K.X. Bastos, Associate Professor, D.Sc., Departamento Engenharia Civil, Universidade Federal de Viçosa, Campus Universitário, Viçosa, MG, Brazil. e-mail: rkxb@ufv.br.
L.S. Betim, Environmental Engineer, M.Sc., Departamento Engenharia Civil, Universidade Federal de Viçosa, Campus Universitário, Viçosa, MG, Brazil. e-mail: luizabetim@gmail.com.
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diverse entomofauna act during putrefaction of cadavers (Üçisik & Rushbrook, 1998; Vass, 2001).

Approximately 60% of a coffined human corpse is readily degradable matter, 15% is moderately degradable, whereas 20% is slowly degraded and 5% is considered inert (Environmental Agency, 2004). The rate of decay depends on the extent of microbial growth and activity. This is influenced by (i) the availability of nutrients (carbon, nitrogen, phosphorus, sulphur) and moisture - the high water content of a corpse and the favorable carbon : nitrogen: phosphorus ratio in vertebrate bodies (about 30:3:1) encourages rapid degradation of the corpse; (ii) pH - neutral pH conditions are most favorable; (iii) climate - warm temperatures accelerate decomposition; (iv) soil lithology - well-drained soil will accelerate decomposition, whereas poorly drained soil has the reverse effect; and (v) burial practice - depth of burial and coffin construction control the ease with which invertebrates/ vertebrates may gain access to the corpse and hasten its decay (Rodriguez & Bass, 1985; Environmental Agency, 2004). A human corpse normally decays within 10 to 12 years, however it is estimated that over half of the pollutant load leaches within the first year and halves year-on-year. Less than 0.1 per cent of the original loading may remain after 10 years (Environmental Agency, 2004).

Cemeteries leakage may eventually work its way down to the groundwater underlying the site. This is influenced by rainfall and infiltration or by the direct contact of buried remains with the water table. The risk of contamination is therefore related to soil's nature and infiltration rate, types of burials, and the effect of rainfall on the groundwater level (Üçisik & Rushbrook, 1998). Pathogens may be retained in the unsaturated soil zone, mainly due to filtration and adherence to clay particles, and eventually die off due to lack of nutrients and reduced soil moisture, increased temperature, and soil pH outside the range of 6 to 7. Thus, pathogenic organisms may be prevented to reach the groundwater due to the relative immobility and attenuation in the soil (Morgan, 2004). However, decomposition of bodies in a grave site promotes soil wetness and the nutrient-rich seepage may favor pathogen survival (Engelbrecht, 1998).

Thus, it is imperative that the authorities with control over construction of cemeteries follow adequate criteria, addressing both environmental and health risks, making regulatory decisions based on available geological and hydrological studies of the area in question, and relying on construction and sanitary techniques (Üçisik & Rushbrook, 1998; Brasil, 2003; Environmental Agency, 2004.). The aim of this paper is to present a preliminary evaluation of groundwater contamination by a cemetery in southeast Brazil.

2. Material and Methods

2.1. Description of the study area

The cemetery studied is located in Tabuleiro, a small town in Minas Gerais state, southeast Brazil (Fig. 1). The total surface area of the cemetery is approximately 15,000 m^2 and it is located in the central region of the town, at a local river flood plain. It is surrounded by dwellings and small commercial buildings. Burial started in second half of twenty century and it is carried out mainly by inhumation or by burial in niche. The average depth of burial into soil is 3.5 m. The soil type in the cemetery area is predominantly gleysol with high clay content. Local temperatures range from 11 to 36 ºC. Average annual rainfall at the closest station (Coronel Pacheco - 30 km from Tabuleiro) is approximately 1.580 mm, varying from 20-47 mm to 200-310 mm during the dry and rainy seasons, respectively (Fig. 2).

2.2. Monitoring wells

Five wells were drilled within the cemetery area for water samples collection and the groundwater level monitoring. Wells 1, 2, 3 and 5 were drilled essentially at the same topographical level, whereas well 4 was located upstream. In addition, an existent well located outside the cemetery area, and in an upper position on flow direction, was used as a control (Fig. 3). All wells were drilled up until 4.5 m depths, above water level, even during dry season, in order to allow water samples collection.

All wells were drilled using SPT percussion boring equipment and accordingly to NBR 12244/1992 (ABNT, 1992). On those wells were installed 3 inches (diameter) monitoring wells with PVC pipes with a 1.0 m long screwed section wrapped in Bidim® geotextile (filtering tips) at the end of each hole. The filtering tip was completely under water during rainy season and partially under water during dry season. The ring space between the bore-

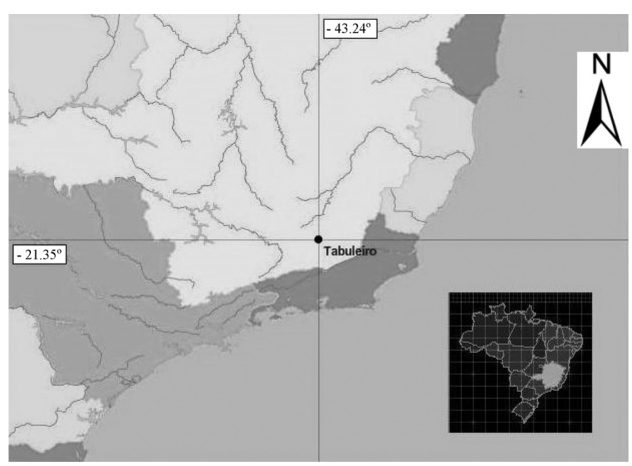

Figure 1 - Location of Tabuleiro, Minas Gerais state (highlighted in the small map), Brazil.

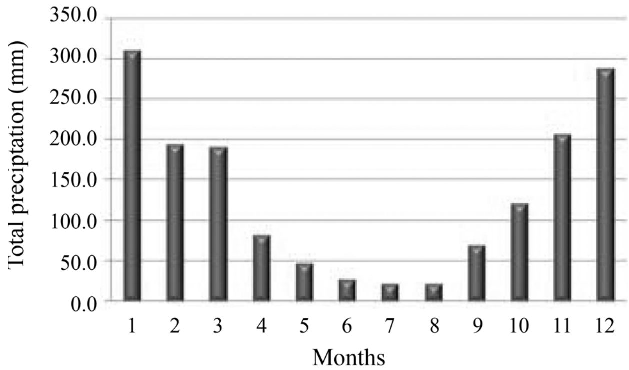

Figure 2 - Average total precipitation at Coronel Pacheco station, located 30 km from Tabuleiro cemetery.

hole cavity wall (with four inches diameter) and the PVC pipe was filled with sand up until 0.50 m above the end of each filtering tip. The remaining space was filled with soil excavated on the same borehole. The final 0.20 m were filled with cement, and a cement slab was installed around the borehole mouth, on the ground surface. At the top of the well, a locked cap was installed to avoid tampering and water leakage.

2.3. Samples collection and analysis

Samples were collected from the five monitoring wells from August 2007 to February 2008 according to the schedule shown in Table 1, thus covering both dry (August to November) and rainy (December to February) seasons. In September 2007 and in February 2008 additional samples were also collected from the control well.

Groundwater aquifer flow was defined throughout the evaluation of water level position measured on those monitoring wells in September 2007 and in March 2008 (Fig. 4).

Bailer sampling devices were used to collect samples from all five wells. To prevent cross-contamination, different bailers were used in each sampling well. All underground water samples were collected after purging the wells. Water samples were conditioned in 500 mL polyethylene disposable bottles, stored on ice inside thermal containers and taken to the laboratory in the same day, where they were kept frozen until the chemical analysis were carried out. Microbiological analysis took place within 24 h after sampling.

Water samples were analyzed in the laboratory for biochemical oxygen demand (BOD), chemical oxygen demand (COD), potassium (K), sodium (Na), calcium (Ca), magnesium (Mg), ammonia (N-NH_3), nitrate (N-NO_3), total phosphorus (P), total coliforms (TC), and *Escherichia coli*. On-site measurement of electrical conductivity, temperature and pH were carried out at each sampling occasion. All these parameters were analyzed according to the guidelines set forth by the Standard Methods for the Examination of Water and Wastewater (APHA, 1998). TC and *E. coli* were

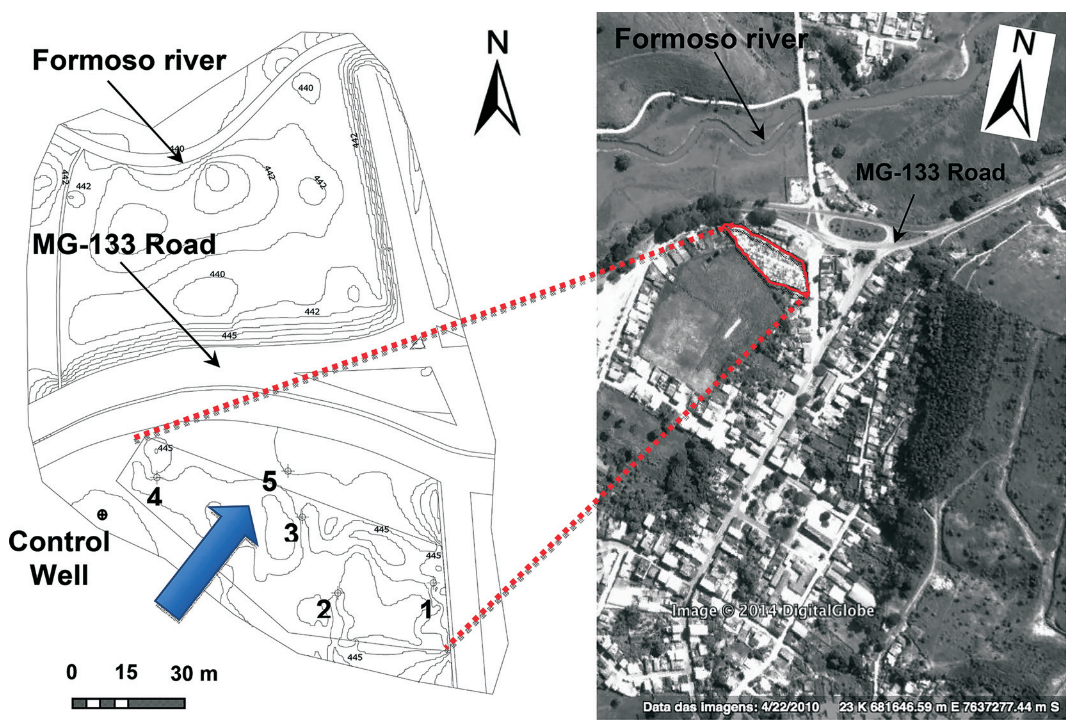

Figure 3 - On the left, the topography of the cemetery area (within straight lines on the South of the road) and its vicinities, and location of the monitoring wells, Tabuleiro-MG, Brazil. Blue dart show the groundwater flow direction. On the right, a satellite image (Google Earth, 2014) showing the cemetery (limit in red) and its vicinity.

Table 1 - Parameters analyzed in water samples from the sampling wells within the cemetery area, Tabuleiro-MG, Brazil, August 2007 to February 2008.

Parameters	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7
	Aug/07	Sep/07	Oct/07	Dec/07	Jan/08	Feb/08	Mar/08
Temp.	X	X	X	X	X	X	
pH	X	X	X	X	X	X	
EC	X	X	X	X	X	X	
P	X	X	X	X	X		
N-NH_3		X	X	X	X	X	
N-NO_3	X	X	X	X	X	X	
Na		X	X	X	X		
K		X	X	X	X		
Ca	X	X	X	X	X	X	
Mg	X	X	X	X	X	X	
BOD		X	X	X	X		
COD	X	X	X		X	X	
Total coliforms				X	X		
E. coli				X	X		

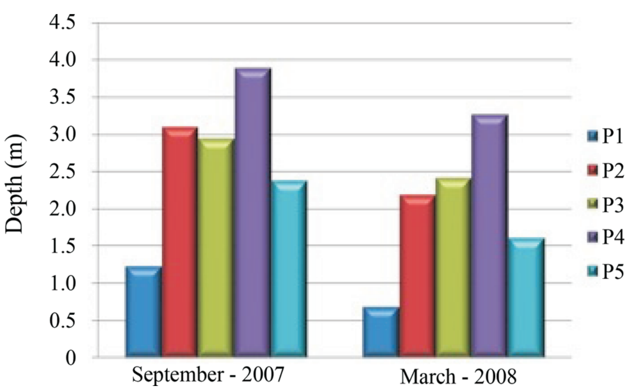

Figure 4 - Water table depth on monitoring wells on September/2007 (beginning of rainy season) and March/2008 (end of rainy season).

enumerated using the enzymatic substrate method (Colilert®).

3. Results and Discussion

3.1. Groundwater level

All groundwater levels were measured at the same day. During the dry season (September 2007) groundwater levels in wells 1 and 5 were, respectively, 1.20 m and 2.38 m below surface. Conversely, in February 2008 during the raining season, the groundwater level raised approximately 0.50 m for well 1 and 0.80 m for well 5, reaching 0.68 m and 1.60 m below surface, respectively. In the other monitoring wells, groundwater level varied from 0.50 m (well 3) to 0.90 m (well 2) from dry to raining season. Because they were at deeper position than wells 1 and 5 during the dry season, groundwater level measured on those monitoring wells during the raining season remained at least 2 m below surface (Table 2).

3.2. Geological-geotechnical characteristics of the area

The cemetery is installed on flood plains of Formoso River. The alluvium sediments on this area are mainly composed by clay, silt and fine sand (more sparse). The geological-geotechnical profile observed up until the maximum depth excavated on the boreholes (4.5 m) is mainly composed by three layers. The first one is a landfill found close to the surface and with a thickness varying from 0.1 to 0.3 m. Below this superficial layer lays a reddish clayey soil with thickness varying from 2.0 m to 3.0 m. At the end of

Table 2 - Ground water level in the monitoring wells during dry and raining seasons, Tabuleiro-MG, Brazil, 2007-2008.

Well	Aug 2007	Feb 2008	Well depth
1	1.22	0.68	2.00
2	3.11	2.19	3.50
3	2.95	2.42	3.50
4	3.90	3.28	4.50
5	2.38	1.60	3.00

Obs.: All measures in (m).

the soil sequence observed on the boreholes there is a grey silty, locally with fine sand, soil layer with 1.5 m thickness. The main geotechnical characteristic of those soils related to the purpose of the study is the permeability. In order to determine this property, two SPT boreholes were specifically done inside the cemetery area in order to allow the realization of permeability tests. On both boreholes, three permeability tests were carried out at 1.5, 2.5 and 3.5 m depth. The average permeability for each of these depths obtained from those tests were:

- 1.5 m depth = 2.00×10^{-6} cm/s;
- 2.5 m depth = 5.50×10^{-7} cm/s; and
- 3.5 m depth = 1.05×10^{-4} cm/s;

These results are in accordance with the texture observed on the boreholes at those depths, as long as there is a more impervious material close to the surface, related to the presence of the reddish clayey soil layer; and a more permeable layer at higher depths, related to the presence of the grey silt material.

3.3. Groundwater bacteriological quality

Total coliforms and *E. coli* were measured only from samples 2 and 4 (in the end of dry season or in beginning of the rainy season), and afterwards in samples 5 and 6 (by the end of the rainy season). In wells 1 to 4 total coliforms were only occasionally detected, mostly in rather low numbers, whereas higher counts were usually found in wells 2 and 5, ranging from 2.4×10^3 organisms per 100 mL (sample 2) to 7.4 (sample 2). *E. coli* was never detected in wells 1 to 4, but was in well 5 and, as with total coliforms, in decreasing numbers from the beginning (7.6×10^2 *E. coli*/100 mL in sample 4) towards the end of the rainy season (7.4 *E. coli* /100 mL in sample 6) (Table 3). It is worth noticing that the microbial counts found in well 5 (and essentially only there) is consistent with the groundwater flow direction and with the relatively shallow water table in this well compared to others (Fig. 3 and Table 2).

Table 3 - Total coliforms and *E. coli* numbers (NMP/100 mL) in groundwater samples during the raining season, Tabuleiro, MG, Brazil, 2007-2008.

Sample	Well	Total coliforms	*Escherichia coli*
2 (Sep 2007)	1	7.4	ND
	2	ND	ND
	3	6.5×10^2	ND
	4	2.4×10^3	ND
	5	1.0	ND
4 (Dec 2007)	1	ND	ND
	2	ND	ND
	3	ND	ND
	4	2.0	ND
	5	1.0×10^3	7.6×10^2
5 (Jan 2008)	1	ND	ND
	2	ND	ND
	3	ND	ND
	4	2.3×10^1	ND
	5	2.5×10^2	4.8×10^1
6 (Feb 2008)	1	1.0	ND
	2	ND	ND
	3	1.0	ND
	4	1.0	ND
	5	2.8×10^1	7.4

ND: not detected.

The presence of coliform bacteria in groundwater has long been considered an indicator of contamination by organic material, in particular, faecal material or decomposing flesh (Young *et al.*, 2002). In Australia, Dent & Knight (1998) recorded variable but low numbers of faecal coliforms, faecal streptococci and *Pseudomonas aeruginosa* in piezometers placed within a burial ground. Pacheco *et al.* (1991), examining three cemeteries with shallow water tables in Brazil, found significant total and faecal coliforms and faecal streptococci. In addition, lipolytic and proteolytic bacteria were found in large numbers, indicating that the products of organic decomposition were being actively transported to the groundwater. Sulfide-reducing *Clostridia* were also frequently detected. Measurements at a control site away from the cemeteries showed an absence of lipolytic and proteolytic bacteria in groundwater. Furthermore, the presence and counts of all these indicator organisms were statiscally correlated. Similar results were found by Rodrigues & Pacheco (2003) in three cemeteries in Portugal. In South Africa, Engelbrecht (1998) showed increased numbers of indicators organisms in well points in a cemetery, as compared to the reference groundwater quality at a municipal borehole. The 95 percentile values for each indicator was found to be: 7.8×10^4 faecal coliforms per 100 mL, 5.7×10^4 *E. coli* per 100 mL, 2.1×10^5 faecal streptococci per 100 mL, and 5.4×10^3 *Staphylococcus aureus* per 100 mL. All these results, including those of the present study, suggest that in some hydrogeological settings microbial organisms can be carried into de groundwater.

3.4. Physical and chemical groundwater quality

Overall, the pH registered throughout the monitoring period ranged from 6.0 to 7.0, which did not substantially differ from the pH of water samples collected from the control well (Fig. 5). Such results suggest that the pH readings do not convey further inferences on eventual impacts of the cemetery upon the local aquifer. Electrical conductivity (EC) tests clearly indicated impacts upon groundwater quality, especially at monitoring well 5 (Fig. 6) located down-

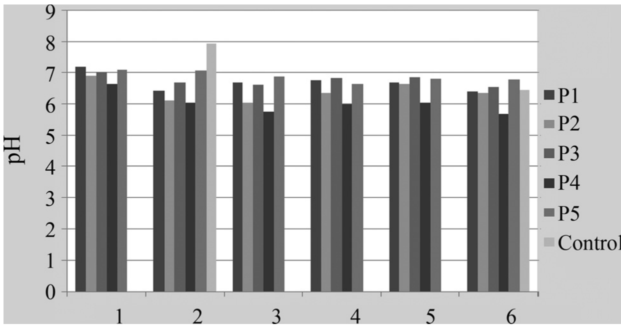

Figure 5 - pH readings in ground water samples, Tabuleiro, MG, Brazil, 2007-2008.

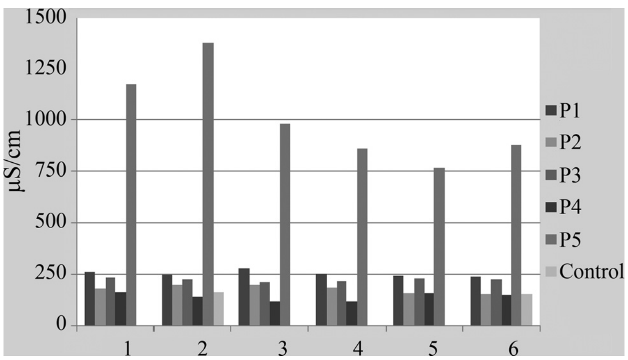

Figure 6 - Electrical conductivity readings in ground water samples, Tabuleiro, MG, Brazil, 2007-2008.

stream from the cemetery both for superficial and underground flow. Monitoring wells 1 to 4, as well as the control one, recorded EC levels ranging from 120 to 280 μS/cm suggesting low salinity. EC in well 5 was much higher, ranging from 770 to 1380 μS/cm, typical readings for saline or wastewaters (Rhoades *et al.*, 1992; Metcalf & Eddy, 2004). The higher EC readings at well 5 maybe associated to its higher levels of ammonia, calcium, magnesium and sodium (Table 4). On Table 5 statistical values for all measured parameters are presented. These results, however, do not convey further inferences on eventual and aggregated impacts of rainfall.

In all groundwater samples, but those from well 5, ammonia remained below detection limit (5 mg/L) (Table 4). In well 5 the ammonia content was even higher than that usually found in municipal sewage (von Sperling & Chernicharo, 2005). These results indicate contamination from on the local aquifer; but as with EC, it does not convey further inferences on eventual and aggregated impacts of rainfall.

Nitrate concentration in groundwater samples varied from 2.5 to 6.4 mg/L in wells 1, 2, 3 and 5, although lesser values were sometimes found in well 5; the exception to its behavior was the result for well 1 at the end of dry season (32.8 mg/L). Taking into account the nitrate content recorded in the control well, overall the results indicate impacts on the aquifer, mostly on well 4 in which higher concentrations were found: around 6 to 8 mg/L during the dry season and from 6 to close to the usual guideline value for drinking-water (10 mg/L) during the rainy season (WHO, 2004). Given that the presence of ammonia and nitrates can be taken as an evidence of pollution and based upon the results found during the study period, it is most likely that the cemetery is a continuous source of ammoniacal nitrogen, especially downstream in sampling well 5, which showed high levels of ammonia, lacking therefore the required time to allow the nitrification cycle to take place both in the soil and in the groundwater.

The content of phosphorus in the sampling wells was low, which is consistent with its low mobility in the soil (Table 4). In general, the results do not indicate that the cemetery is sourcing phosphorus to the aquifer. Nevertheless, is worth noticing that higher concentrations were usually found in well 5 (located downstream) during the rainy season.

A comparison between calcium readings in the sampling wells and in the control well clearly suggests that the cemetery is impacting the aquifer; moreover this pattern is more evident in sampling well 5. The results also suggest some seepage of magnesium, although not as clear as for calcium (Table 4). Overall there was little evidence of sodium contribution from the cemetery into the groundwater. Notwithstanding, once again well 5 usually showed the highest concentrations of sodium (Table 4). In general potassium is found only in very low concentrations in groundwater. Thus, in spite of being found in low concentrations in the wells, there is some suggestion of the cemetery as a source of potassium feeding the aquifer. The concentrations found in sample 1, are clearly an exception and could be attributed to the presence of clay in the samples collected from the wells.

BOD concentration on groundwater samples was usually low; in contrast COD values were much higher. Thus the recorded high COD: BOD ratios suggest that the groundwater was polluted by organic matter least biodegradable or at its initial degradation stages. However, it should be noted that the control well revealed an unexpected high COD reading in sample 6.

The observed impact of burial ground effluent on groundwater is generally similar to that of landfill leachate. The common contaminants are labile organic compounds, ammoniacal nitrogen, mobile anions (*e.g.* Cl, NO_3 and SO_4) and alkali earth metals (*e.g.* Na, K) (Young *et al.*, 2002; Sawyer *et al.*, 2003). The physical and chemical parameters analyzed herein are among those usually recommended as monitoring guidelines and as a first approach for detecting the groundwater impacts from cemeteries (Environmental Agency, 2004; Tredoux *et al.*, 2004). Further, the findings of this study are in general agreement with those by others. For instance, high concentrations of ammonium and nitrate ions have been reported in a contamination plume which

Table 4 - Chemical groundwater quality, Tabuleiro, MG, Brazil, 2007-2008.

Sample	Well	$N\text{-}NO_3$	$N\text{-}NH_3$	BOD	COD	P	Ca	Mg	Na	K
1	1	32.8	NM	NM	60.0	0.01	21.2	5.9	13.2	110.0
	2	3.7	NM	NM	85.0	0.14	14.4	4.3	11.4	83.6
	3	6.4	NM	NM	111.0	0.03	39.7	6.2	NM	NM
	4	6.4	NM	NM	126.0	0.02	20.4	3.6	6.8	83.6
	5	6.4	NM	NM	82.4	NM	31.7	2.8	81.4	70.4
	Control	NM	NM	NM	NM	NM	NM	NM	NM	NM
2	1	4.0	< 5.0	0.3	75.2	0.04	20.4	14.8	2.8	9.8
	2	3.8	< 5.0	1.5	27.3	0.07	18.8	11.2	2.2	5.0
	3	5.2	< 5.0	1.6	268.4	0.19	38.5	11.7	3.4	9.4
	4	8.0	< 5.0	0.4	110.5	0.05	20.4	NM	2.2	4.2
	5	1.5	73.5	6.1	126.6	0.09	35.3	NCO	1.6	1.4
	Control	1.0	< 5.0	0.4	57.1	0.11	16.0	16.0	12.0	3.2
3	1	4.4	< 5.0	3	27.3	0.06	32.9	0.9	10.4	5.2
	2	3.1	< 5.0	NM	57.1	0.09	23.2	NM	5.2	2.8
	3	2.4	< 5.0	3	27.3	0.10	38.1	NM	1.8	0.8
	4	7.6	< 5.0	2	27.3	0.06	15.2	NM	2	0.8
	5	7.4	NM	10	110.5	0.09	60.9	5.2	15.6	5.8
	Control	NM	NM	NM	NM	NM	NM	NM	NM	NM
4	1	3.3	< 5.0	3	NM	0.02	24.8	5.3	10.3	4.0
	2	4.8	< 5.0	3	NM	0.03	15.6	1.2	8.8	3.8
	3	4.6	< 5.0	6	NM	0.03	34.9	1.0	3.3	0.8
	4	6.1	< 5.0	5	NM	0.01	13.6	0.5	4.5	0.5
	5	0.5	45.7	2	NM	0.11	44.5	17.0	21.5	7.0
	Control	NM	NM	NM	NM	NM	NM	NM	NM	NM
5	1	4.8	< 5.0	NM	110.7	0.01	16.4	4.1	10.4	3.2
	2	4.3	< 5.0	NM	111.3	0.03	12.4	0.5	5.2	2.2
	3	6.2	< 5.0	NM	111.3	0.03	36.1	1.5	3.4	0.4
	4	9.2	< 5.0	NM	110.4	0.0	16.8	1.5	4.8	0.6
	5	0.6	68.9	NM	109.4	0.17	38.5	4.4	14.6	4.2
	Control	NM	NM	NM	NM	NM	NM	NM	NM	NM
6	1	5.2	< 5.0	NM	110.4	0.01	12.0	1.0	11.0	3.2
	2	4.1	< 5.0	NM	107.8	0.02	8.4	1.9	5.4	2.0
	3	4.9	< 5.0	NM	110.7	0.11	29.7	1.0	4.6	0.4
	4	9.8	< 5.0	NM	110.0	0.01	9.2	0.2	5.4	0.2
	5	0.3	33.3	NM	98.0	0.09	44.9	5.7	16.2	3.8
	Control	0.4	< 5.0	NM	109.8	0.01	11.2	1.7	6.0	2.2
7	1	4.9	< 5.0	2	108.5	0.07	17.6	3.4	NM	NM
	2	3.8	< 5.0	1	108.7	0.02	11.6	0.7	NM	NM
	3	5.0	< 5.0	3	109.4	0.13	33.7	0.5	NM	NM
	4	9.8	< 5.0	2	109.6	0.03	14.8	0.2	NM	NM
	5	0.5	< 5.0	8	106.3	0.27	40.1	3.2	NM	NM
	Control	0.6	< 5.0	3	109.8	0	16.0	1.0	NM	NM

NM: not measured; NCO: Not collected. All units are ($mg.L^{-1}$).

Table 5 - Average values and variation coefficients of chemical parameters

Well	Value	$N\text{-}NO_3$	$N\text{-}NH_3$	BOD	COD	P	Ca	Mg	Na	K
1	Average	4.43	< 5.0	2.08	82.02	0.03	20.76	5.06	9.68	5.08
	Std. Dev.	0.63	N.D.	1.10	31.24	0.02	6.21	4.36	3.24	2.47
2	Average	3.94	< 5.0	1.83	82.87	0.06	14.91	3.30	6.37	3.16
	Std. Dev.	0.49	N.D.	0.85	31.23	0.04	4.54	3.75	2.95	1.11
3	Average	4.96	< 5.0	3.40	123.02	0.09	35.81	3.65	3.30	2.36
	Std. Dev.	1.22	N.D.	1.61	71.78	0.06	3.17	4.08	0.89	3.52
4	Average	8.13	< 5.0	2.35	98.97	0.03	15.77	1.20	4.28	1.26
	Std. Dev.	1.52	N.D.	1.66	32.57	0.02	3.65	1.29	1.71	1.48
5	Average	2.46	55.35	6.53	105.53	0.14	41.80	4.26	13.90	4.44
	Std. Dev.	2.84	16.53	2.95	13.39	0.07	4.71	1.12	6.60	1.90
Control	Average	0.67	< 5.0	1.70	92.23	0.04	14.40	6.23	9.00	2.70
	Std. Dev.	0.25	N.D.	1.30	24.84	0.05	2.26	6.91	3.00	0.50

NM: not measured; All units are in ($mg.L^{-1}$).

rapidly diminished with distance from graves in Germany, whereas in Holland a very saline (2300 μS/cm) plume of chloride, sulfate and bicarbonate ions was found beneath graves. Studies in Australia showed an increase in electrical conductivity close to graves; also, elevated chloride, nitrate, nitrite, ammonium, orthophosphate, iron, sodium, potassium and magnesium ions were found beneath the cemetery. Index measures of organic contamination, including total organic carbon (TOC), BOD and COD have also been reported in groundwater analyses form burial grounds (Üçisik & Rushbrook, 1998). In the above mentioned work of Engelbrecht (1998) an increase in concentration above the regional groundwater quality was found for several chemical parameters in well points inside the cemetery; the maximum recorded values were: 37 mg K/L, 88.9 mg NH_3/L, 55.4 mg NO_3+NO_2/L, 0.99 mg PO_4/L, and 218 dissolved organic carbon per liter. In two of the three cemeteries studied by In Brazil, Pacheco *et al.* (1991) found nitrate concentrations as high as 2.1 and 75.7 mg/L. Similar results have been reported by Migliorini (1994), who observed high concentrations of nitrogenous products in the groundwater of Vila Formosa Cemetery (São Paulo, Brazil), and this was found to be a direct result of human remains' decomposition. Migliorini (1994) also came across high concentrations of calcium in the groundwater of Vila Formosa Cemetery, but suggested that the use of lime in the cemetery was the most probable source of calcium. On the other hand, it is well known that saponification reactions in corpses could be a source of calcium and magnesium (Fiedler & Graw, 2003).

In general, water samples have shown underground water contamination, but further studies are necessary to define whether this contamination is caused by corpse decomposition and/or by other sources such as septic tanks or malfunctioning of sewage systems.

4. Conclusions

The results arising from this study adds further evidence that groundwater is subjected to contamination from burials leakage from cemeteries. The studied cemetery, as several other existing burial grounds in Brazil, was sited without any prior geological and hydrogeological assessment, thus not surprisingly the most evident impacts have been observed in the sampling well located downstream of the cemetery site. Such impacts were confirmed mainly by the following water quality parameters: electrical conductivity, ammoniacal nitrogen, nitrates, calcium, COD, total coliforms and *Escherichia coli*. It must be pointed out that these last two parameters (total coliforms and *Escherichia coli*) cannot be related to corpse decomposition, but its presence must be related to sources existing in the cemetery surroundings, as there are no administration or visitors services within the cemetery area.

The evidences resulting from this study shows that there is a need of addressing a more detailed characterization of cemeteries leakages, including pathogenic organisms and toxic amines, and the fate of chemical and microbial contaminants from cemeteries trough the soil. Proper hydrogeological assessments of new or extension of existing burial sites must be sought to mitigate environmental impacts and health risks.

The results have shown contamination of underground water but this cannot be definitely pointed as only been derived from Tabuleiro Cemetery leakage.

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