Effect of the decommissioned Roger open dump in João Pessoa-Paraíba-Brazil on the local groundwater quality

Gilson Barbosa Athayde Júnior
Civil Engineer by *Universidade Federal da Paraíba*, PhD (Sanitary Engineering) by University of Leeds – United Kingdom. Professor at Civil and Environmental Engineering Department, Centre of Technology, *Universidade Federal da Paraíba*, Castelo Branco, João Pessoa-PB, Cep: 58.051-900. E-mail: gilson@ct.ufpb.br

Claudia Coutinho Nóbrega
Civil Engineer by Universidade Federal da Paraíba, Doctor in Natural Resources by *Universidade Federal de Campina Grande.* Professor at Civil and Environmental Engineering Department, Centre of Technology, Universidade Federal da Paraíba, Castelo Branco, João Pessoa-PB, Cep: 58.051-900. E-mail: claudiacn@uol.com.br

Carmem Lúcia Moreira Gadelha
Civil Engineer by Universidade Federal da Paraíba, Doctor in Sanitary Engineering by *Universidade de São Paulo*. Professor at Civil and Environmental Engineering Department, Centre of Technology, *Universidade Federal da Paraíba*, Castelo Branco, João Pessoa-PB, Cep: 58.051-900. E-mail: carmemgadelha@yahoo.com.br

Giulliano de Sousa Fagundes
Civil Engineer by *Universidade Federal da Paraíba*, Master in Urban and Environmental Engineering by *Universidade Federal da Paraíba*, Universidade Federal da Paraíba, Bairro Castelo Branco, João Pessoa-PB, Cep: 58.059-900. E-mail: giulliano_fagundes@yahoo.com.br

Diego Rodrigo dos Santos Machado
Undergraduate student in Environmental Engineering at *Universidade Federal da Paraíba*. Research stuent (*Iniciação científica CNPq/UFPB*). Universidade Federal da Paraíba, Bairro Castelo Branco, João Pessoa-PB, Cep: 58.059-900. E-mail: dirsmachado@yahoo.com.br

Irene Monteiro da Franca Souza
Civil Engineer by *Universidade Federal da Paraíba*. Former Research stuent (*Iniciação científica CNPq/UFPB*). Universidade Federal da Paraíba, Bairro Castelo Branco, João Pessoa-PB, Cep: 58.059-900. E-mail: irenesouza1984@hotmail.com

ABSTRACT

Throughout 45 years (1958-2003) the solid wastes from João Pessoa, state of Paraíba, Northeast Brazil, were disposed off in the former Roger's open dump, which is situated adjacent to the mangrove at the sides of Sanhauá river. Several environmental concerns results from this inadequate disposal of solid wastes, including the pollution of groundwater nearby the former Roger's open dump, which is the major point of investigation of this paper. Groundwater quality from 5 wells situated in the region of influence of the open dump were monitored from March 2006 until April 2009. Results have shown that the groundwater nearby the open dump cannot be drunk by the population without previous treatment, since it have presented some parameters of water quality in discordance with Brazilian legislation concerned to drinking water. Results have also shown that degree of pollution is higher in the wells closer to the open dump.

Key-words: groundwater; pollution; open dump.

1) INTRODUCTION

Water is a natural resource very abundant on Earth surface and is essential for life. Through human history, people always tried to set home close to water. Nowadays, people make several uses of water, such as energy generation, navigation, irrigation, fishing, urban supply and others. Because of that, water is very important for economical and social development. Public health is also affected by water availability and quality. Water-related diseases can occur by ingestion of polluted water or little water availability and are responsible for millions people death, including those of children. These figures could be reduced if good quality water is sufficient supplied for people.

Groundwater is in an important part of water supply. In comparison to surface water, groundwater presents several advantages with regards to its quality, because it is well protected from most pollution sources. By the other side, rapid urban and industrial growth associated with population growth, make wastes generation to increase, so that pollution control measures and wastes disposal alternatives have to be efficient. Unfortunately, wastes disposal is not at the desirable and necessary level in most Brazilian cities and other places in the world. In such localities, wastes are disposed off in open dumps, jeopardizing natural resources, including the groundwater. Nowadays, the pollution of groundwater by leachate originated in open dumps sites or even in well designed landfills is common. Therefore, many usages of this water may be jeopardized.

This paper have the objective of analyzing water quality in the region of the decommissioned Roger's open dump in João Pessoa, the capital of the state of Paraíba, in Northeast Brazil, and investigate if this open dump contributes to local groundwater degradation.

1.1 Groundwater quality

Part of rainwater reaches the soil and infiltrates. This water percolates the soil and accumulates in the voids and rocks fractures, making up the aquifers or water tables. Along the pathways of water through the soil, a natural filtration process takes part. This process occurs very slowly and is responsible for the good water quality and makes it generally suitable for human consumption.

Water table is fed by rainwater and surface water, and occasionally come up, giving origin to water springs, rivers and lakes. The close relationship between these waters, make possible that one contaminates the other. Contaminated soil by agro-industrial pesticides, sewage or even contaminated surface rainwater flow, are same of groundwater pollution sources. Once contaminated, groundwater is very difficult to the remediated and water usages are jeopardized, mainly the human consumption use.

Water in pure state is not found in nature. Along the several phases of hydrological cycle, it dissolves and transports the impurities present in the environment. Chemical composition of groundwater depends on local aquifer lithology. According to ANA (2002), because water prolonged contact time with soil and rocks, groundwater is more mineralized than surface water. In general, some constituents such as bicarbonate, calcium, chlorides and magnesium are present in concentration as high as 5mg/L, while carbonate, fluoride and iron are present in concentrations between 0,01 and 5 mg/L and trace elements are present in concentration bellow 0,01 mg/L.

1.2 Groundwater pollution from open dumps

Many cities do not dispose off their waste properly. In many cases, wastes are disposed off in open dumps, resulting in environmental matters because air, soil and water contamination by leachate, which is a dark liquid, resulted from anaerobic decomposition of organic matter. Leachate is of difficult biodegradability and results in high pollution loads. It also contains heavy metals such as lead, nickel and aluminium that make it dangerous for the environment.

Because soils in open dumps are not watertight, leachate infiltrates reaching groundwater. A plume of contamination may be formed, posing risks for people using the groundwater. Once contaminated, the negative effects may last of decades and the length may be longer than the area of waste disposal.

Hypolito and Ezaki (2006) in a study on landfills in São Paulo (Brazil) found that the influence of wastes decomposition is higher in water from wells situated at downstream as compared to water from wells at upstream in relation to groundwater flow. These authors detected high concentrations of iron and manganese ions in groundwater under influence of a landfill and concluded that the reducing conditions from the environment lead the higher mobility of metals ions. These authors reported pH values in the acid band in such waters. Coelho and Santos (2004) also found higher level of contamination in groundwater downstream a landfill, when reporting a study in Uberlândia (Brazil).

Abu-Rukah and Al-Kofari (2001) evaluated the effects of leachate on the groundwater quality near the landfill attending the city of Al-Akader, north Jordan. They selected 11 wells nearby the landfill and concluded that pollution level is higher as proximity of landfill is higher. Most of parameter exceeded the limits for drinking water for that country.

Souza and Naval (2000) presented an study in which upstream and downstream groundwater quality in the landfill of Cuiabá (Brazil) differed from each other in terms of BOD_5 and nutrients. Still in Cuiabá (Brazil), Santos *et al* (2009) studied the correlation between organic matter and other water quality variables in the groundwater. They found high levels of BOD_5 and COD, and concluded that the groundwater presented high level of pollution.

Lopes *et al* (2007) studied the influence from the landfill of São Carlos (Brazil) on local groundwater quality. Downstream wells presented high salinity values, as opposed to those from other wells. Ammonia concentrations were 10-15 times higher in downstream wells as compared to those in upstream wells. Both upstream and downstream wells presented ammonia concentration higher than the permissible value according Brazilian legislation for drinking water, suggesting that other sources of pollution, in addition to the landfill, may be present. Heavy metals concentrations were high as well. Iron, manganese, aluminium were among the metals detected, although only iron is known to be naturally presents in the region soil. Those authors concluded that the landfill has contaminated the local groundwater.

In a study on several wells near a landfill in Ribeirão Preto (Brazil), Piaí et al, (2006) found lead and selenium level above the permissible value according Brazilian legislation for drinking water.

Pujari et al., (2007) studied groundwater contamination nearly the landfill of Nagpur (India) and found higher values of electrical conductivity in the downstream wells as compared to those from upstream wells. In general, water quality was not in accordance to drinking water standards for that country.

Ideriah et al (2006) found that organic matter levels in groundwater are lower as the distance from a landfill in Port Harcourt (Nigéria) increases. They concluded that the landfill contributes to groundwater contamination. According to these studies it can be concluded that wastes disposal sites, such as open dumps and landfills, are potential source of groundwater contamination.

From these studies reported, it can be concluded that open dumps and landfills can contaminate groundwater, so that water quality monitoring must be carried out near these waste disposal sites.

1.3 Regulation relative to drinking water in Brazil

Drinking water is defined as that suitable for human consumption and that microbiological, physical, chemical and radioactive parameters attend to the standards set for drinking water. In Brazil, drinking water standards are set by the Portaria 518/2004, from Health Department (Ministério da Saúde). Table 1 show Maximum Permissible Values (MPV) for drinking water quality standards in Brazil.

Table 1. Brazilian drinking water standards

Parameter	MPV (1)	Unit
E. coli or thermotolerant coliform	Absent in 100 ml	
Turbidity	1 (2)	TU
Ammonia	1,5	mg/L
Nitrite	1,0	mg/L
Nitrate	10	mg/L
Lead	0,01	mg/L
Aluminium	0,2	mg/L
Color	15	uH
Hardness	500	mg/L
Total dissolved solids	1000	mg/L
Chloride	250	mg/L
pH	6,0 – 9,5 (range)	-

Source: BRASIL (2004).

2) METHODOLOGY

João Pessoa, the capital of Paraíba State, in northest Brazil, is the most populated city in the state, with 723.514 inhabitants in the year 2010. The former Roger's open dump is situated adjacent to the mangrove at

Sanhauá River, started operation in 1958 and lasted until 2003, when Municipal Department of Justice established its closure on August 5. In João Pessoa, basically only two seasons occurs: rainy and dry. Rainfall index was 1787 mm/year during 2006-2009 (period of this study). Air temperature varies from 24 to 26 °C.

Initially, four wells were selected in the region of the former Roger's open dump (P1, P2, P3 and P4). Subsequently, more two wells were made inside the open dump area (P5 and P6). These wells are shown in figure 1, in which the yellow line is the boundary of the open dump and the red line is a water stream that flows adjacent to the open dump.

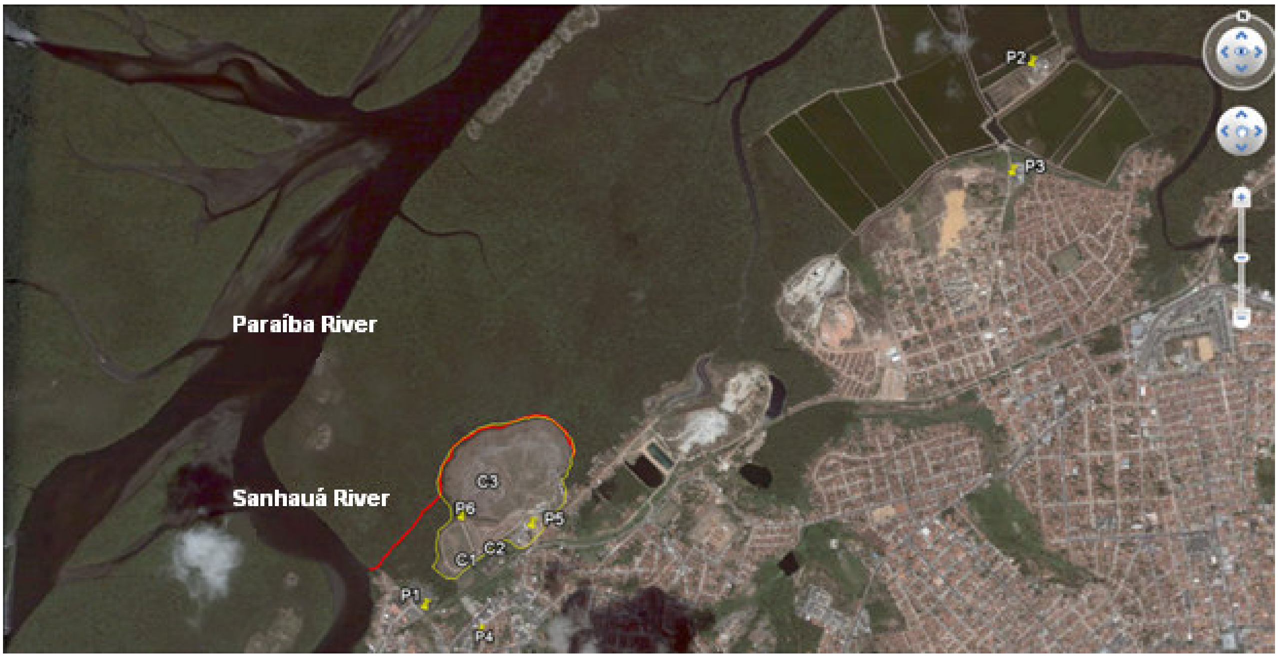

Figure 1 – Aerial photograph (Google Earth) from the studied area

P1 is a deep well (deeper than the calcareous layer) that reach the confined aquifer (Beberibe aquifer), while P4 is a surface spring. P2 and P3 are wells located at a shrimp farm, being the first a shallow one (Barreiras not confined aquifer) and the second a deep one (Beberibe aquifer). Both P5 and P6 are shallow wells (7m in depths) made in the internal area of the former open dump. Table 2 shows the geographic coordinates of the wells.

Table 2 - Summary of the location and description of sampling points

Collections Points	**Latitude**	**Longitude**	**Description**
P1	7° 6'39.96"S	34°53'16.60"W	In the área of direct inffluence
P2	7° 5'33.84"S	34°51'55.47"W	In the área of indirect inffluence
P3	7° 5'18.11"S	34°51'53.41"W	In the área of indirect inffluence
P4	7° 6'43.27"S	34°53'8.54"W	In the área of direct inffluence
P5	7° 6'27.60"S	34°53'1.89"W	In the area inside the former open dump
P6	7° 6'26.87"S	34°53'11.99"W	In the area inside the former open dump

Samples of each well were collected in the following dates: 08/03/2006, 09/08/2006, 07/11/2006, 28/02/2007, 06/06/2007, 12/09/2007, 05/12/2007, 20/04/2008, 23/07/2008, 26/11/2008, and 22/04/2009. Collection of samples were always done in the morning period (8-11h), Samples were taken to the Sanitation Laboratory at the *Universidade Federal da Paraíba* (in João Pessoa) and processed. Access to P4 was denied from 06/06/2007 on, and for this season, data from this well is not included in this paper. Parameters analyzed were: pH, electrical conductivity, hardness, color, turbidity, BOD_5, COD, oil and greases, chlorides, ammonia, nitrite, nitrate, lead, aluminium and thermotolerant coliform. Physico-chemlical and bacteriological analysis followed recommendation of APHA et al., (1998).

The Kolmogorov-Swirnov test for normal distribution was used (Sokal and Rohlf, 1981). For comparison between means, the analysis of variance at the level of 5% of significance according to the GT-2 method was used (Sokal and Rohlf, 1981).

3) RESULTS

Topographic level in P5 and P6 differed in 3 meters, showing that groundwater flows from P5 and P6. Results obtained were compared to the drinking water standards according to Brazilian legislation (Portaria MS 518/2004). According to the Komogorov-Smirnov test applied, 76,24% of data distribution were normal. In the 23,75% of the other cases, data distribution were atypical.

Table 3. shows descriptive statistic (arithmetic mean, minimum and maximum values, number of the) for all the parameters analyzed in this study.

Table 3 – Descriptive statistics of the data collected

Arithmetic mean		
Minimum value	Maximum value	Number of determinations

Parameter	Unit	P1			P2			P3			P5			P6		
pH	-	7,01			7,33			7,29			6,49			6,35		
		6,67	7,27	11	7,01	7,64	11	7,02	7,64	11	5,20	7,26	7	5,00	7,32	9
Electrical Conductivity	µS/cm	532			380			414			948			1102		
		295	752	11	300	614	11	307	652	11	550	1342	7	645	1950	8
Hardness	mg/L	321			204			309			2026			5320		
		288	389	11	180	215	11	144	361	11	987	3452	7	301	11851	9
Color	mg/L	1,1			0,4			0,2			290,7			240,2		
		0,0	5,0	11	0,0	5,0	11	0,0	2,5	11	120	600	7	0	400	9
Turbidity	NTU	0,2			0,5			1,2			81,3			88,3		
		0,1	0,7	11	0,2	0,8	11	0,1	3,9	11	5,5	152,0	7	3,9	59,0	9
BOD_5	mg/L	2			1			1			144			159		
		0	9	11	0	7	11	0	1	10	89	330	7	0	420	9
COD	mg/L	7			10			6			427			441		
		4	18	9	2	45	11	1	10	10	278	632	7	8	735	9
Oil and Grease	mg/L	5,5			2,7			3,8			2,2			10,6		
		2,1	28,7	10	2,1	5,0	9	2,1	11,2	9	2,1	2,5	6	2,1	21,8	9
Chlorides	mg/L	99			98			100			3747			8692		
		63	145	11	82	125	11	77	195	11	2271	8454	7	87	13452	9
Ammonia	mg/L	0,21			0,23			0,22			279,7			313,6		
		0,00	2,14	11	0,00	2,33	11	0,00	2,20	11	198,0	549,1	7	0,0	738,5	9
Nitrite	mg/L	0,02			0,02			0,02			1,60			1,72		
		0,00	0,10	11	0,00	0,10	11	0,00	0,10	11	0,00	5,30	7	0,00	4,90	9
Nitrate	mg/L	1,15			0,65			0,20			0,23			0,35		
		0,00	6,50	11	0,00	6,00	11	0,00	1,10	11	0,00	1,50	7	0,00	1,60	9
Aluminium	mg/L	0,02			0,02			0,02			6,06			2,01		
		0,01	0,04	10	0,01	0,04	10	0,01	0,04	10	0,10	25,20	7	0,10	18,00	9
Lead	mg/L	0,02			0,02			0,02			0,50			0,40		
		0,00	0,10	10	0,00	0,10	10	0,00	0,10	10	0,50	0,50	6	0,00	0,50	9
Thermot. Coliform (1)	MPN/ 100 mL	11			22			9			95			24		
		0	460	11	0	2400	11	0	43	11	0	640000	7	0	920000	9

(1) For thermotolerant coliform, the geometric mean was applied

Figure 2 presents pH data for sampled wells. All the values remained inside the recommended band for drinking water, exceptionally in November 2008 and April 2009 for P5 and P6. P5 and P6 presented the lower values for pH, possibly associated with organic matter decomposition from the former open dump. Figure 3 shows that there is significant difference between pH mean of P6 and that for P1, P2 and P3. The same occurred between that for P5 and those for P2 and P3. No others significant differences were found.

Figure 4 shows electrical conductivity for all studied wells, which varied from 295 to 792 µS/cm in P1, P2 and P3 and from 632 to almost 2000 µS/cm in P5 and P6. Lopes et al., (2007) and Abu-Rukah and Al-kofari (2001) also reported higher electrical conductivity values in the well closer to a landfill. Graphic comparison of electrical conductivity (figure 5) showed no significant differences between means of P1, P2 and P3. The same occurs for P5 and P6. By the other side, means for P1, P2 and P3 significantly differed from those for P5 and P6.

Figure 6 shows the hardness for wells P1, P2 and P3, while figure 7 shows this parameter for P5 and P6. For P1, P2 and P3 all values remained below maximum permitted value for drinking water, however, for P5 and P6, all the values remained above this limit. Figure 8 shows that the means for hardness in P1, P2 and P3 did not differ from each other, while the means for both P5 and P6 differed from those for P1, P2 and P3 and also from each other.

Figure 9 show color values for P1, P2 and P3. In this case, all the values are below the limit for drinking water. Figure 10 shows colour values for P5 and P6 all the values were above the limit for drinking water. The difference between the group formed by P1, P2 and P3 and that formed by P5 and P6 is great, and as show in figure 11, they significantly differ from each other.

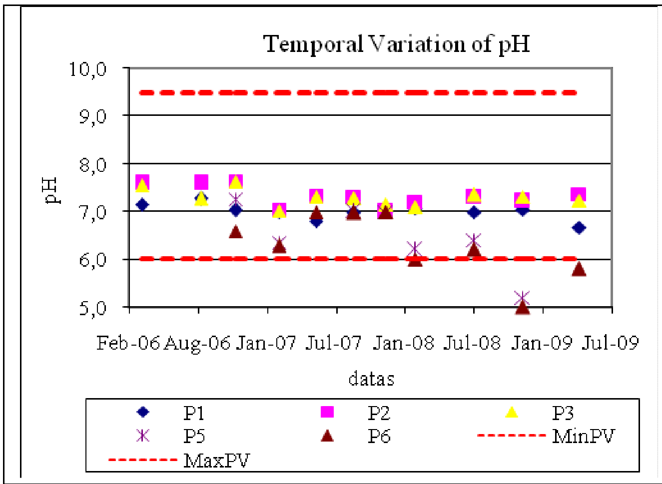

Figure 2: Temporal variation of pH.

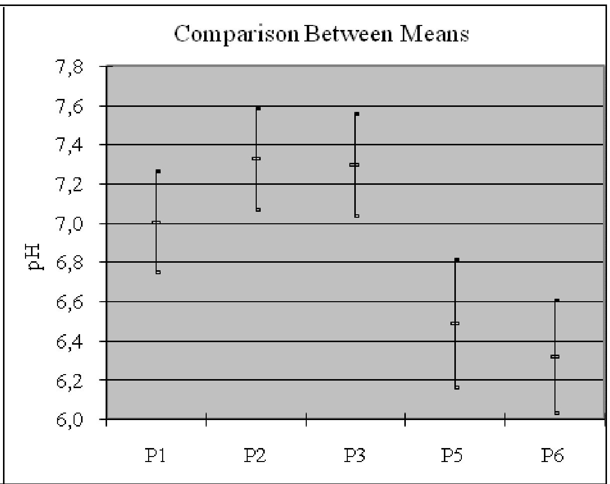

Figure 3: Comparison between means of pH.

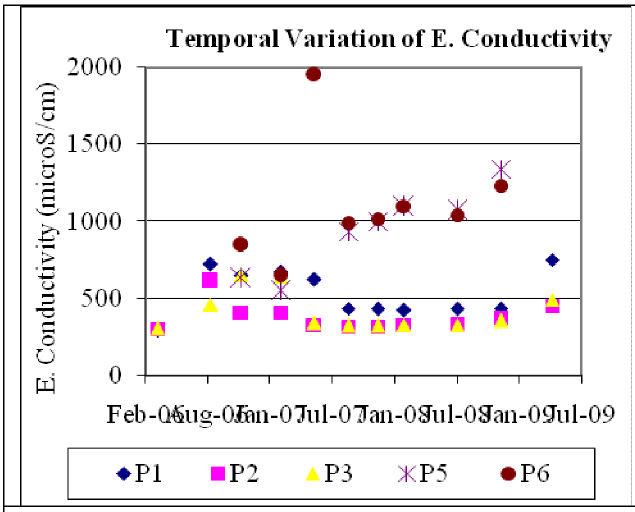

Figure 4: Temporal variation of electrical conductivity.

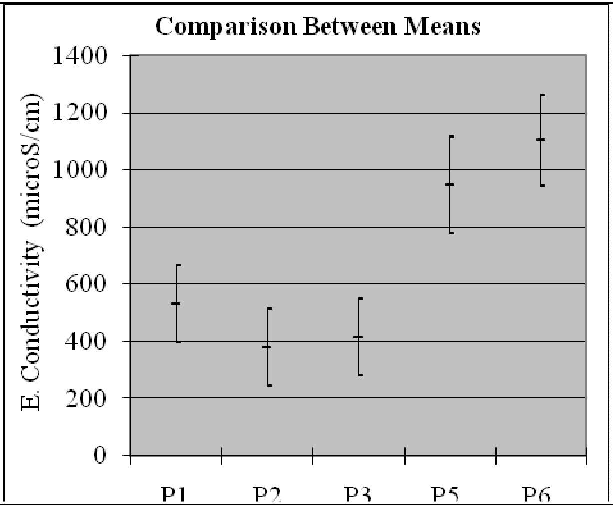

Figure 5: Comparison between means of electrical conductivity.

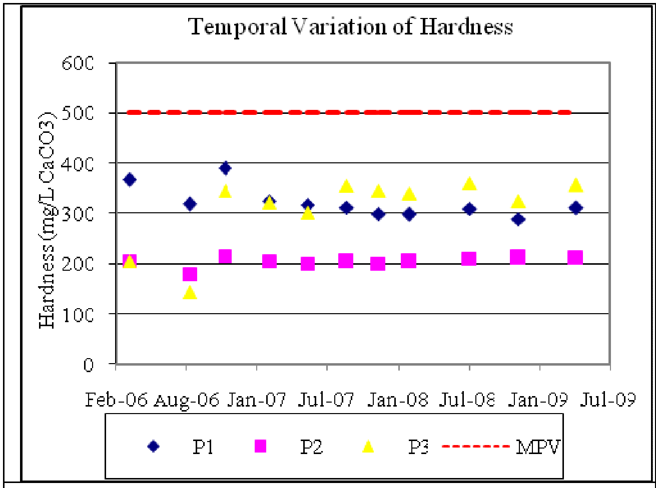

Figure 6: Temporal Variation of Hardness for wells P1, P2 and P3.

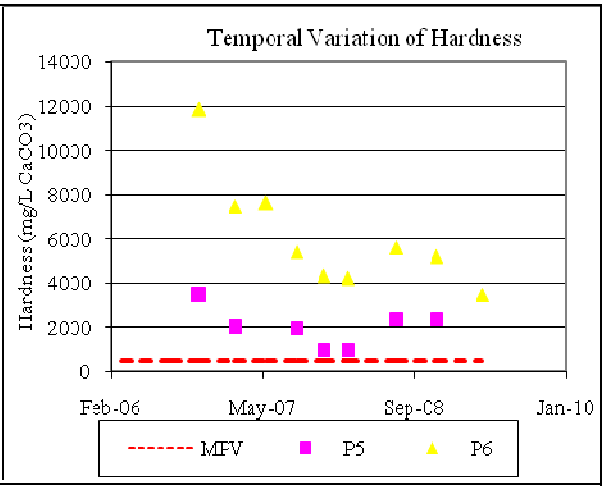

Figure 7: Temporal Variation of Hardness for wells P5 and P6.

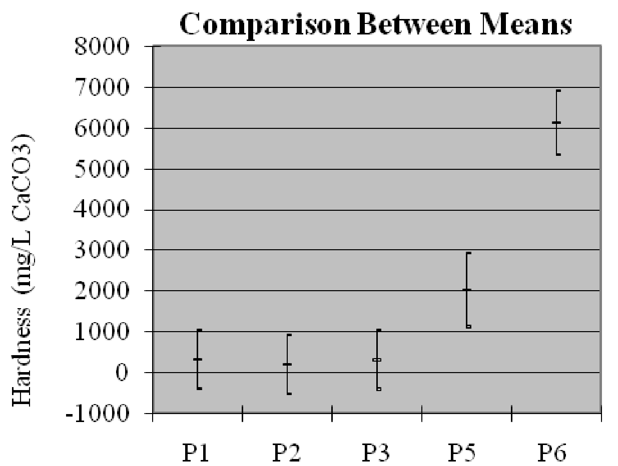

Figure 8: Comparison between means of Hardness

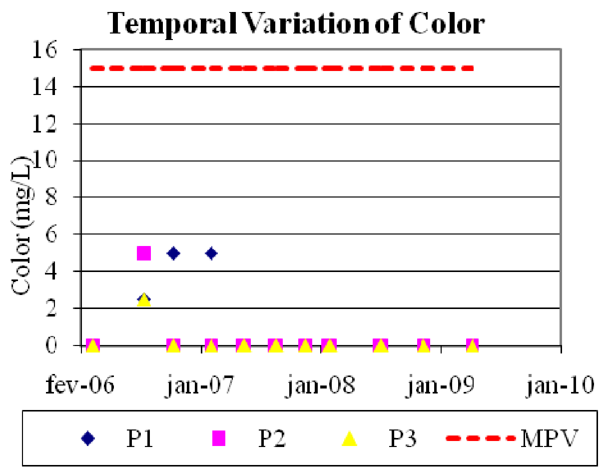

Figure 9: Temporal Variation of Hardness for wells P1, P2 and P3.

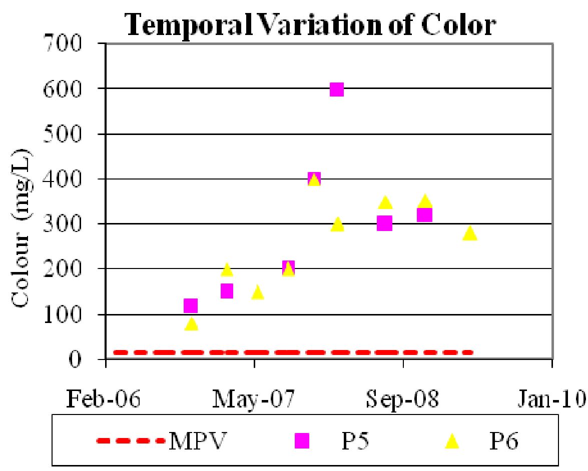

Figure 10: Temporal Variation of Hardness for wells P5 and P6.

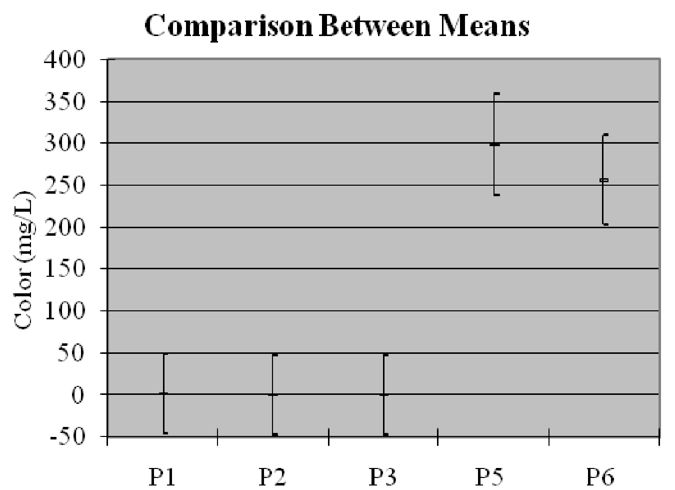

Figure 11: GT-2 analysis for comparison between means of color

Figure 12 shows turbidity values for P1, P2 and P3. Most of values were below drinking water limits. On the other hand, turbidity values for P5 and P6 were very high and above the drinking water limits (figure 13). Means from P1, P2 and P3 did not differ from each other, but differed from those for P5 and P6 (figure 14).

Figure 15 shows BOD_5 concentration for P1, P2 and P3, which varied from nil to 2 mg/L. Figure 16 shows BOD_5 for P5 and P6, which varied from 50 to 200 mg/L. According to Feitosa et al (2008), natural groundwater present BOD_5 below 5mg/L, and in this case, these high values for P5 and P6 denotes high pollutions levels. According to the analysis of variance (17), the means for BOD_5 from P1, P2 and P3 did not differ from each other, but were significantly different from those for P5 and P6. High values of BOD_5 were also detected by Coelho and Santos (2004) when studying groundwater quality in a landfill site.

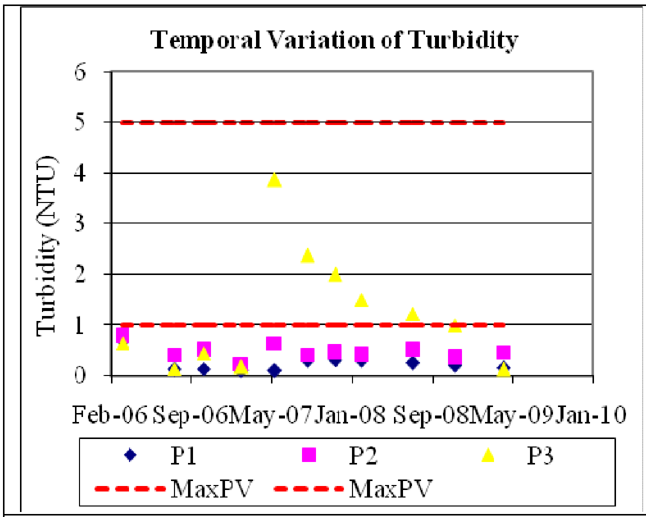

Figure 12: Temporal Variation of Turbidity for wells P1, P2 and P3.

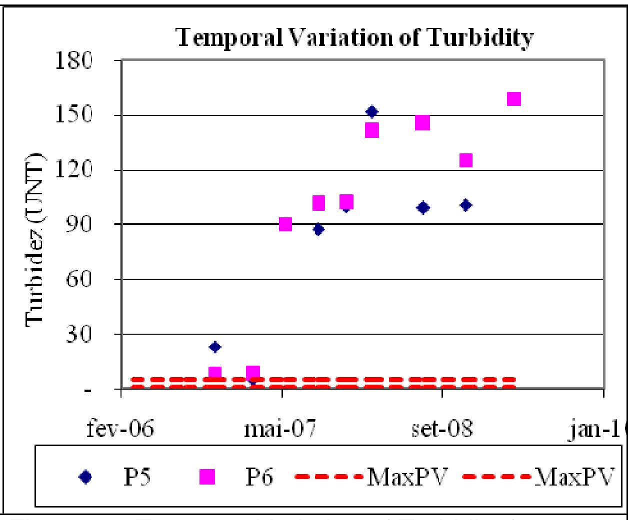

Figure 13: Temporal Variation of Turbidity for wells P5 and P6.

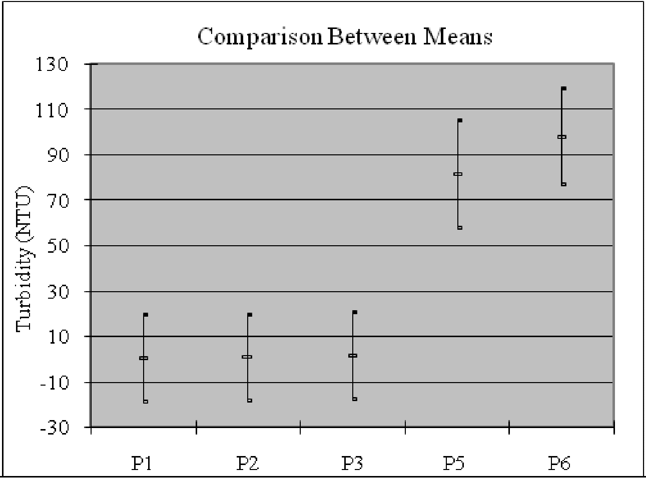

Figure 14: Comparison between means of Turbidity

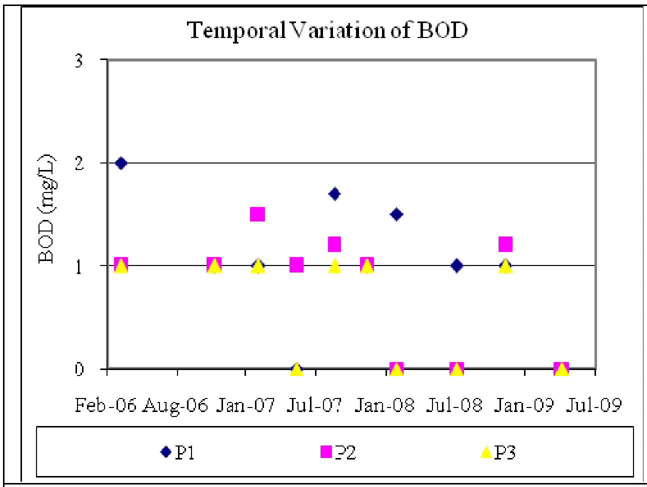

Figure 15: Temporal Variation of BOD_5 for wells P1, P2 and P3.

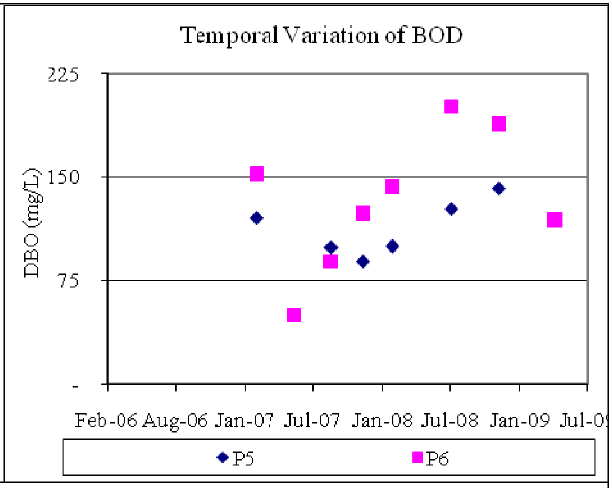

Figure 16: Temporal Variation of BOD_5 for wells P5 and P6.

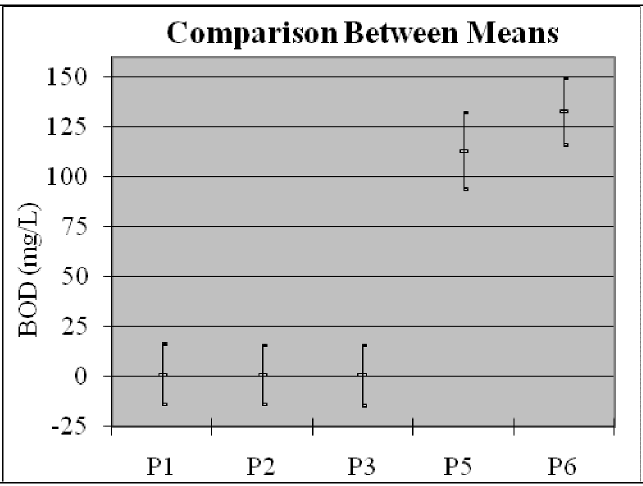

Figure 17: Comparison between means of BOD_5

Figure 18 shows COD concentration for P1, P2 and P3, which varied from 1,2 mg/L to 18,5 mg/L. P3, a deep well, presented the lowest values for COD, accordingly with BOD_5 data. Figure 19 shows COD concentration for P5 and P6, which varied from 278 mg/L to 735 mg/L and are well above these values for P1, P2 and P3. These results are similar to those reported by Lopes et al (2009) and Coelho and Santos (2004). Figure 20 shows comparison between means for P1, P2, P3, P5 and P6. It can be seem that the means for P1, P2 and P3 did not differ from each other, the means for P5 and P6 did not differ from each other as well. However, P5 and P6 presented means that differed from those for P1, P2 and P3.

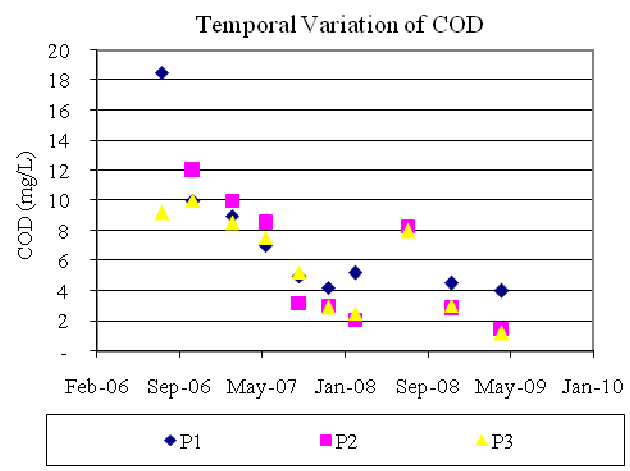

Figure 18: Temporal Variation of COD for wells P1, P2 and P3

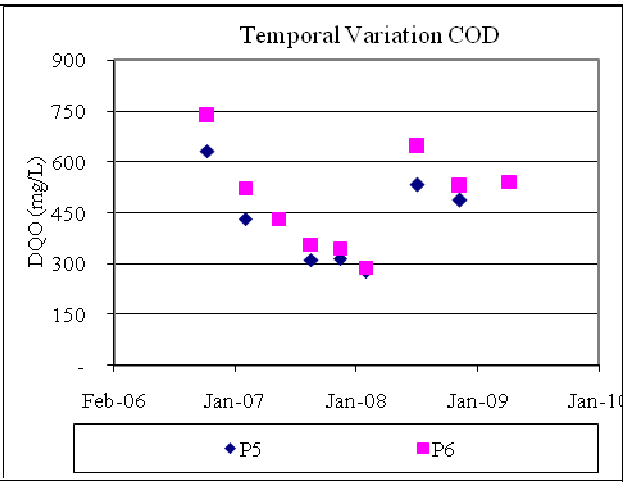

Figure 19: Temporal Variation of COD for wells P5 and P6.

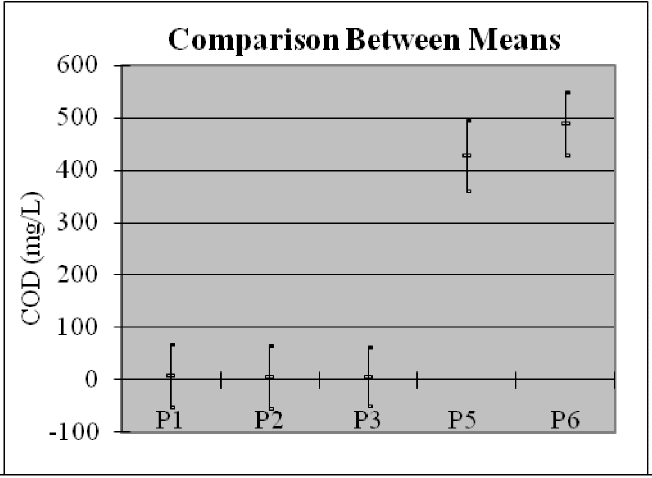

Figure 20: Comparison between means of COD

Figure 21 show oil and grease concentration for all the wells studied. This parameter was detected in all the wells. The mean for P6 significantly differed from those for P1, P2 and P4 (figure 22). This may be associated with groundwater flow direction from P5 to P6.

Figure 23 shows chlorides concentration for P1, P2 and P3, which remained below the limit for drinking water. Figure 24 shows chlorides concentration for P5 and P6, which, in all the cases, presented values above the limit for drinking water. Analysis of variance showed that means from P1, P2 and P3 did not differ from each other. The mean for both P5 and P6 significantly differed from those for P1, P2 and P3 (figure 25).

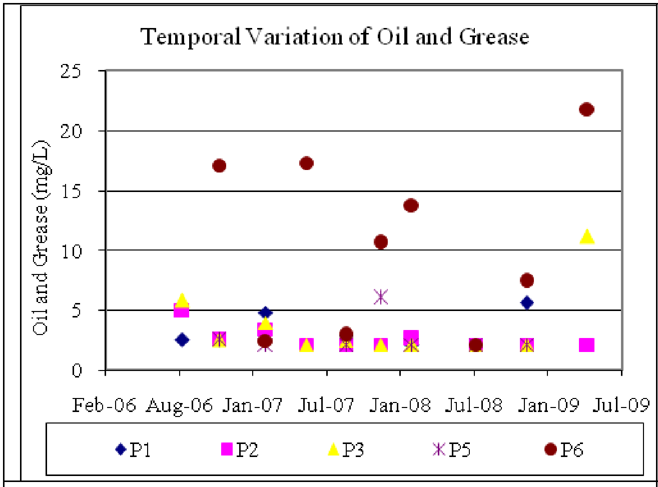

Figure 21: Temporal Variation of oil and grease

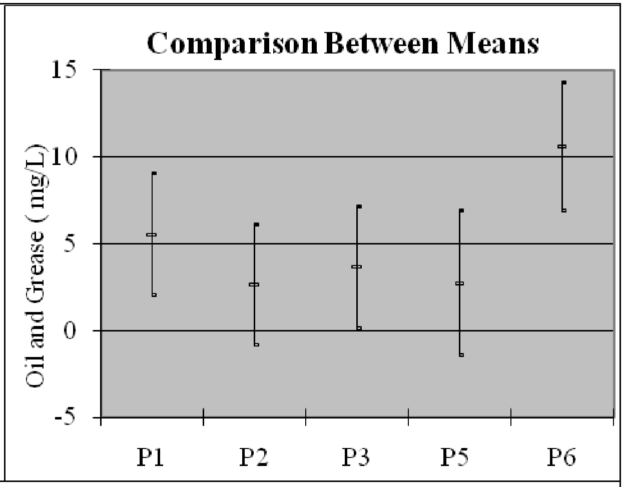

Figure 22: Comparison between means of oil and grease

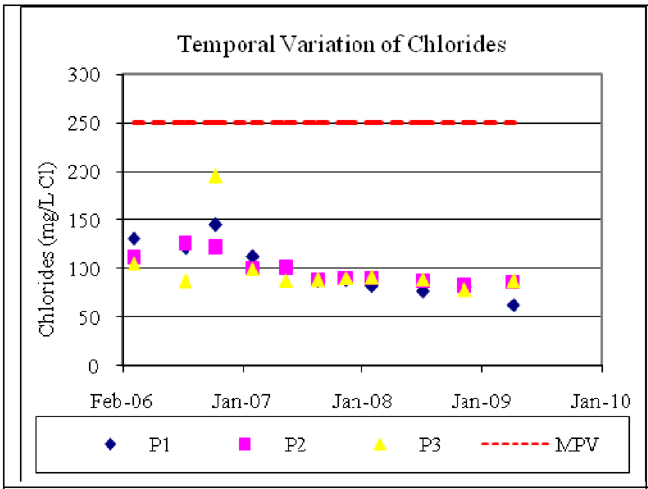

Figure 23: Temporal Variation of Chlorides for wells P1, P2 and P3.

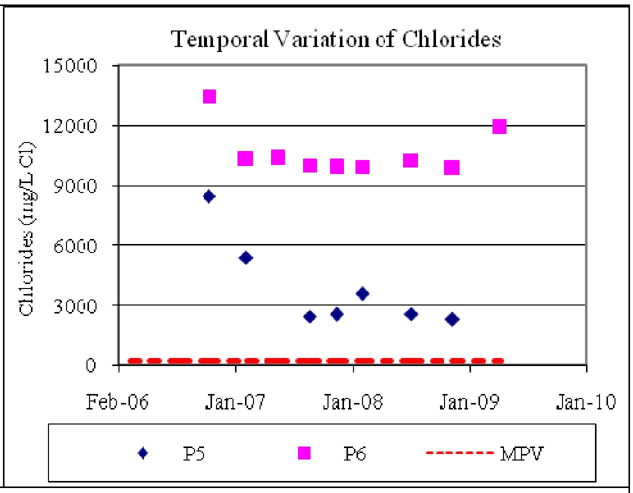

Figure 24: Temporal Variation of Chlorides for wells P5 and P6.

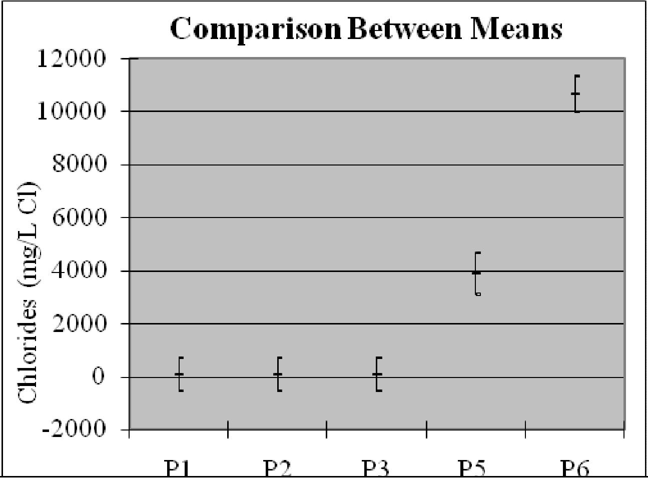

Figure 25: Comparison between means of chlorides.

Figure 26 shows ammonia concentration for P1, P2 and P3, in which it can be seen all the values below the MPV for drinking water. In figure 27, the concentration of ammonia for P5 and P6 are shown, and the values are very high and above MPV for drinking water. P6, which situated downstream in relation to the groundwater flow, presented highest values. Figure 28 shows the comparison between means of the 5 wells. The mean for P1, P2 and P3 does not differ from each other. However, the mean for both P5 and P6 significantly differ from those for P1, P2 and P3.

Figure 29 shows nitrite concentration in all the studied wells. Only P5 and P6 presented concentration above the MPV for drinking water. The mean for P6 significantly differed from those for P1, P2 and P3, but not from that for P5 (figure 30).

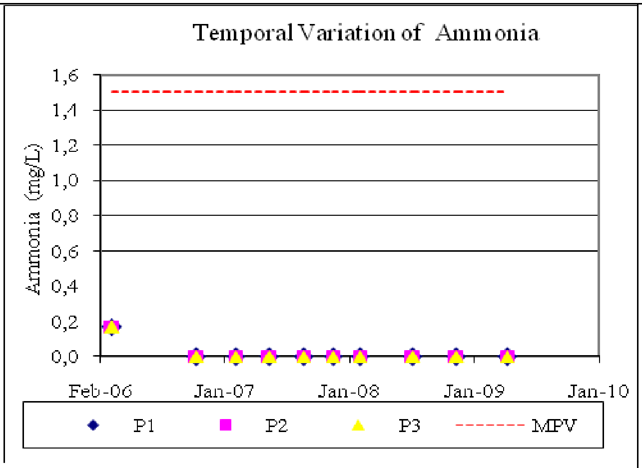

Figure 26: Temporal Variation of ammonia for wells P1, P2 and P3.

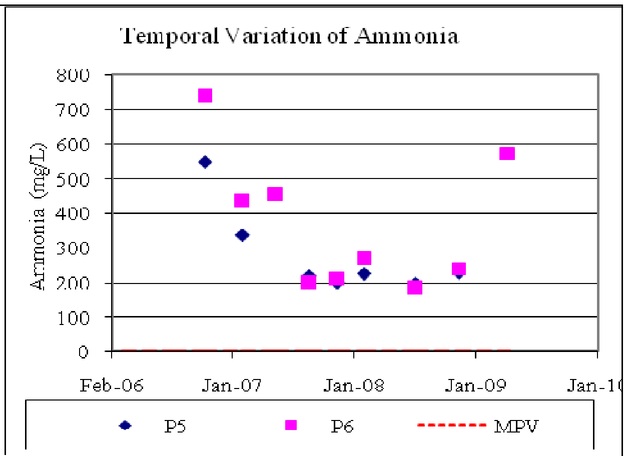

Figure 27: Temporal Variation of ammonia for wells P5 and P6.

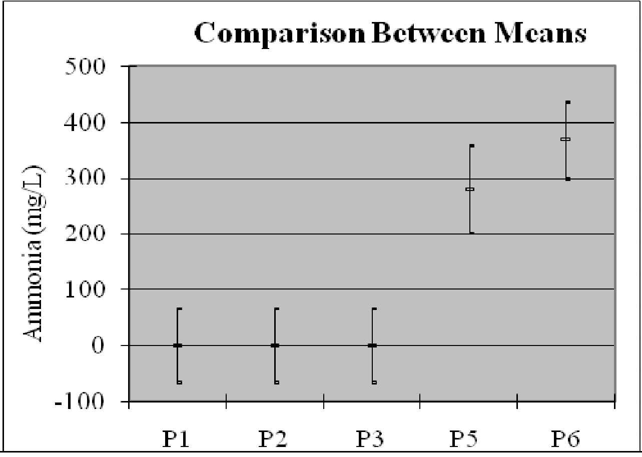

Figure 28: Comparison between means of ammonia.

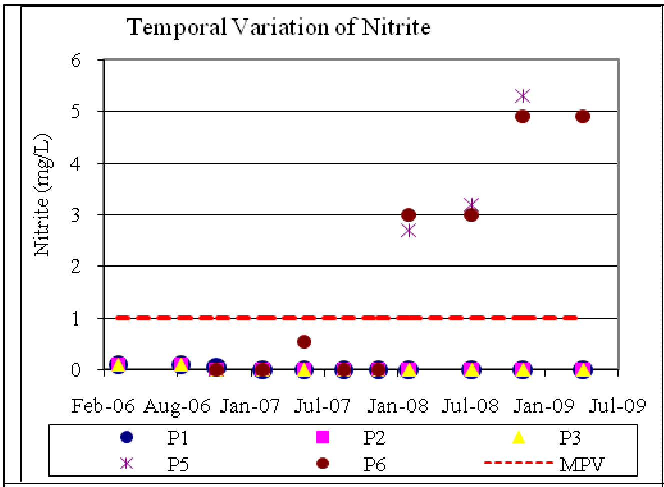

Figure 29: Temporal variation of nitrite

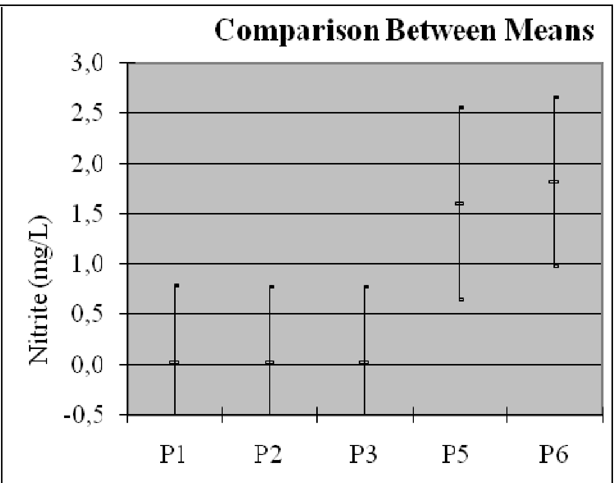

Figure 30: Comparison between means of nitrite.

Figure 31 shows nitrate concentration in all the wells. All the wells presented nitrate concentration below the MPV for drinking water. No mean differed from any other at the level of 5% (figure 32).

Figure 33 shows aluminium concentration in P1, P2 and P3. For these wells, all the values are below the MPV for drinking water. On the other hand, the MPV for drinking water was overlapped in most dates for P5 and P6 (figure 34). No mean differed from any other at the level of 5% of significance (figure 35).

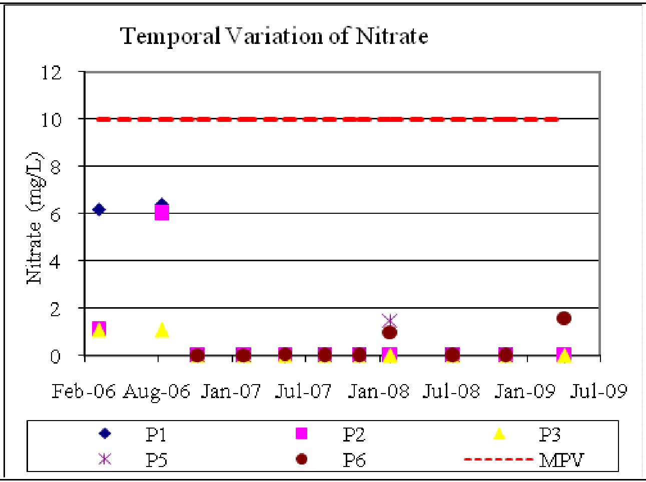

Figure 31: Temporal Variation of nitrate

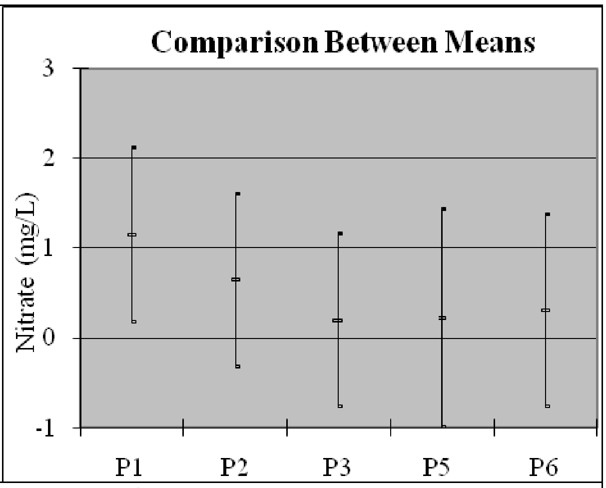

Figure 32: Comparison between means of nitrate.

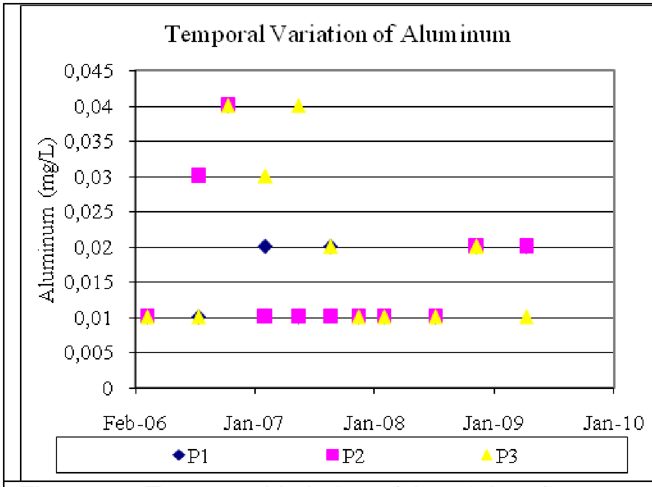

Figure 33: Temporal Variation of Aluminium for wells P1, P2 and P3.

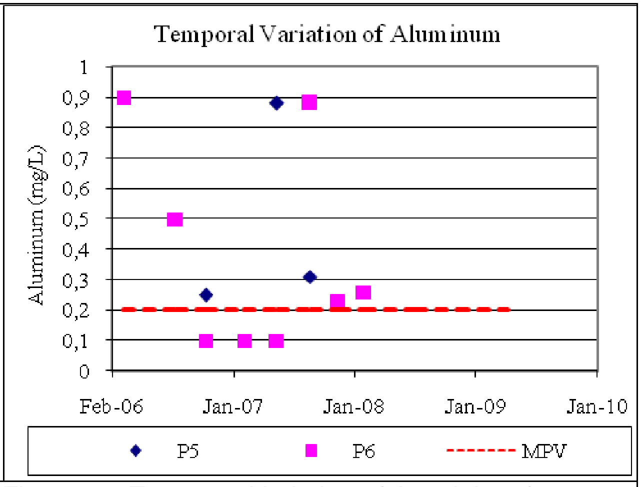

Figure 34: Temporal Variation of Aluminium for wells P5 and P6.

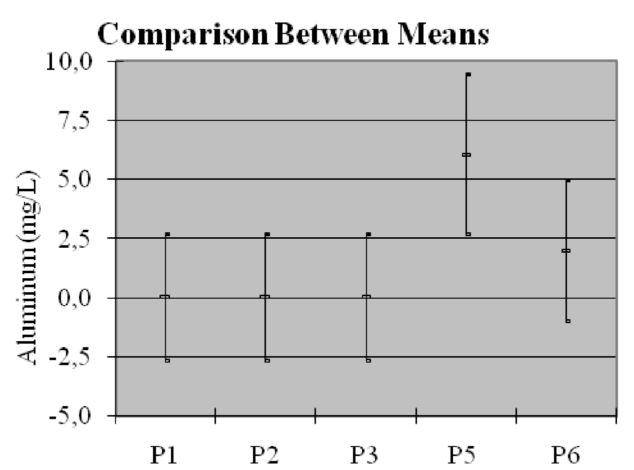

Figure 35: Comparison between means of Aluminium.

Figure 36 shows lead concentration for P1, P2 and P3. All the values equalled or were below the MPV for drinking water. For P5 and P6, most of the values were higher than the MPV for drinking water (figure 37). Figure 38 shows that there is no significant difference between means from P1, P2 and P3. The mean for P5 and P6 significantly differed from those for P1, P2 and P3.

Figure 39 shows that thermotolerant coliform number varied from nil to 10^6 MPN/100ml. There were no significant differences between means from the wells.

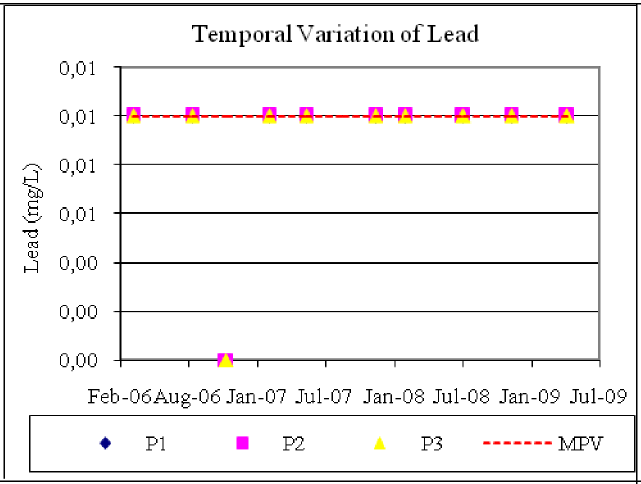

Figure 36: Temporal Variation of Lead for wells P1, P2 and P3.

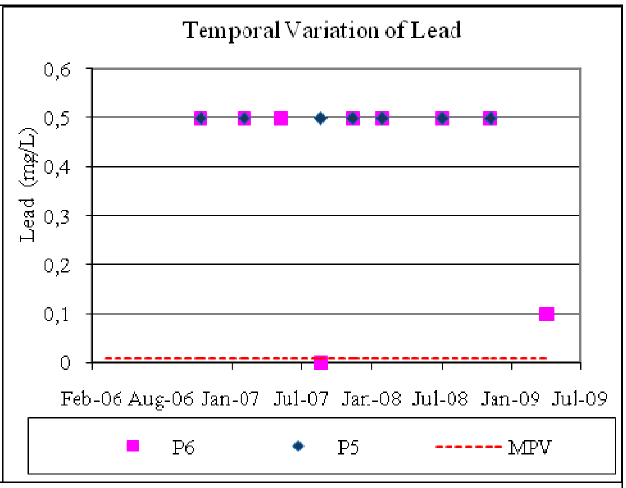

Figure 37: Temporal Variation of Lead for wells P5 and P6.

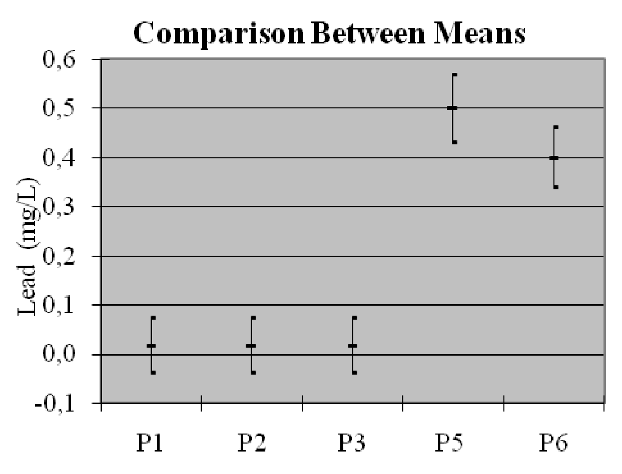

Figure 38: Comparison between means of Lead.

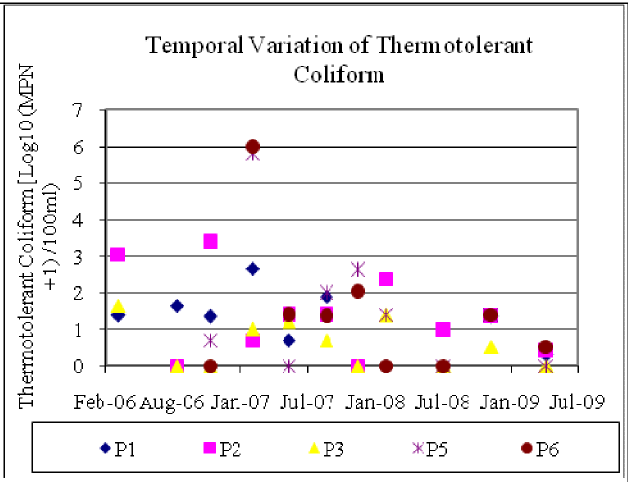

Figure 39: Temporal Variation of Thermotolerant Coliform.

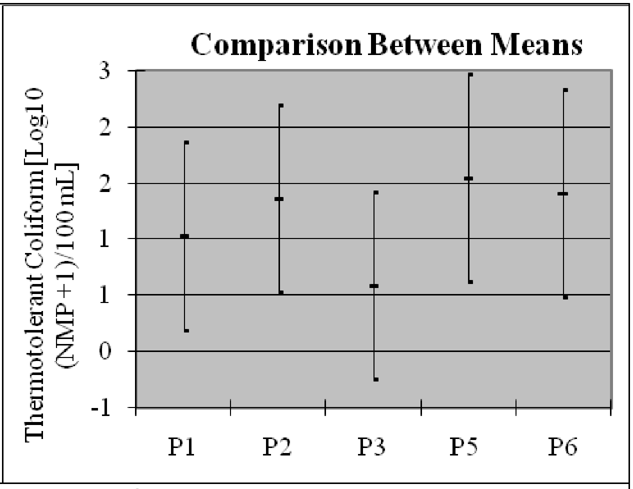

Figure 40: Comparison between means of Thermotolerant Coliform.

6) DISCUSSION AND CONCLUSIONS

Water collected from the 5 wells studied cannot be used for human consumption without previous treatment, since it presents same parameter not in accordance to the Brazilian drinking water standards. This result is no surprisingly, since water herein studied was in the row state (without treatment).

Water quality for P5 and P6 presented the worst quality indicator and can be associated to the proximity to the former Roger's open dump. This result is in accordance to literature reports. For many parameters, the mean for P5 and P6 differed significantly from those for P1, P2 and P3. On the other hand, since ammonia and thermotolerant coliform are pollution indicators of recent discharge, other pollution sources, in addition to the former open dump, may be present at the studied area.

Water quality from P5 and P6 are well correlated with each other. Ten out of sixteen parameters presented significant correlations at the level of 5%. Similar results were found for P1, P2 and P3, where significant correlations were found in nine out of sixteen cases. This suggests that P5 and P6 have a common cause for their water quality, which can be the former Roger's open dump

Analysis of groundwater here in studied showed sufficient evidence that the former Roger's open dump significantly contributes to local groundwater pollution.

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