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WATER QUALITY ANALYSIS OF MONITORING WELLS IN A URBAN SOLID WASTE DISPOSAL AREA IN SOUTHERN BRAZIL

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Resumo

O monitoramento da qualiiddade da água subterrânea em áreas com potencial de contaminação desempenha uma importante ferramenta de gestão. Essa pesquisa teve como objetivo analisar uma série histórica do monitoramento da qualidade da água subterrânea por meio de uma rede de poços na área ocupada por um aterro sanitário localizado na região noroeste do estado do Rio Grande do Sul, entre os anos de 2007 a 2018. Os resultados indicaram alterações nos parâmetros microbiológicas (coliformes totais e termotolerantes) os quais apresentaram maior contribuição relativa dos parâmetros analisados. As variáveis cloreto, nitrato e sulfato também apresentaram alterações no período analisado. Sendo estes, com valores em desacordo com a legislação vigente para o uso de abastecimento humano. Entre os parâmetros analisados, somente o pH apresentou relação com a precipitação. O agrupamento permitiu a formação de grupos específicos, com destaque ao PM03, com características individuais entre os demais. Assim, conclui-se que ocorreram alterações nos parâmetros de qualidade da água entre o período analisado, principalmente na direção do fluxo subterrâneo do aquífero suspenso temporário não contínuo.

Palavras-chave: Aquífero; Água subterrânea; Contaminantes ambientais.

WATER QUALITY ANALYSIS OF MONITORING WELLS IN A URBAN SOLID WASTE DISPOSAL AREA IN SOUTHERN BRAZIL

Abstract

Monitoring groundwater quality in areas with potential contamination plays a critical management tool. This research aimed to analyze a historical series of groundwater quality monitoring through a network of wells in the space occupied by a landfill located in the northwest region of Rio Grande do Sul between the years 2007 to 2018. The results indicated changes in microbiological parameters (total and thermotolerant coliforms) which presented an immense relative contribution of the analyzed parameters. The variables chloride, nitrate, and sulfate also showed changes in the analyzed period. It was these, with values in disagreement with the current legislation for the use of human supply. Among the studied parameters, only the pH was related to the precipitation. The grouping allowed the formation of specific groups, especially PM03, with individual characteristics among the others. Thus, it is concluded that there were changes in the water quality parameters between the analyzed periods, mainly in the direction of the underground flow of the non-continuous temporary suspended aquifer.

Keywords: Aquifer; Groundwater; Environmental contamination.

ANÁLISIS DE LA CALIDAD DEL AGUA DE LOS POZOS DE MONITOREO EN UNA ZONA URBANA DE ELIMINACIÓN DE RESIDUOS SÓLIDOS EN EL SUR DE BRASIL

Resumen

El monitoreo de la calidad del agua subterránea en áreas con gestión. Esta investigación tuvo como objetivo analizar una serie histórica de monitoreo de la calidad del agua subterránea a través de una red de pozos en el área ocupada por un relleno sanitario ubicado en la región noroeste del estado de Rio Grande do Sul, entre los años 2007 a 2018. Los resultados indicaron cambios en los parámetros microbiológicos (coliformes totales y termotolerantes) estos que presentaron mayor contribución relativa de los parámetros analizados. Las variables cloruro, nitrato y sulfato también mostraron cambios en el período analizado. Siendo éstos, con valores en desacuerdo con la legislación vigente para el uso de suministros humanos. Entre los parámetros analizados, solo el pH se relacionó con la precipitación. La agrupación permitió la formación de grupos específicos, con énfasis en PM03, con características individuales entre los demás. Así, se concluye que hubo cambios en los parámetros de calidad del agua entre el período analizado, principalmente en la dirección del flujo subterráneo del acuífero suspendido temporal no continuo.

Palabras-clave: Acuífero; Aguas subterrâneas; Contaminantes ambientales.

1. INTRODUCTION

The process of managing water resources (surface or underground) is one of the main challenges facing society today. Brazil has a large water reserve, both superficial and underground, but the contamination process of these springs has affected its quality.

In the State of Rio Grande do Sul (RS), groundwater plays a crucial role in public supply. According to the National Water Agency (ANA, 2015), 57.50 % of Rio Grande do Sul municipalities are supplied exclusively by groundwater, 13.40 % have a mixed system (surface plus underground), and only 29.10 % are solely provided by springs superficial.

In this context, research involving groundwater quality monitoring is of great importance, especially in activities with the potential to contaminate the environment. Foster et al. (2002; 2006) describe standard groundwater contamination processes, such as solid waste landfill, drainage in industrial areas, leakage from storage tanks, and in situ sanitation.

In solid waste disposal areas, the monitoring process is essential, as it allows the identification of possible sources of contamination arising from the activity, helping in the decision-making process. The monitoring system is carried out using piezometers or monitoring wells (ABNT, 1992; 1997a; 2006; 2007; 2008; 2010; 2017).

Groundwater contamination in solid waste disposal areas, according to Foster et al. (2002; 2006), is mainly composed of general organic loads, heavy metals, salinity, and toxic microorganisms. These compounds come from the percolation of leachate generated in the decomposition of waste through the soil to the vadose zone. Davis and Masten (2016) state that the migration process of contaminants in soil and aquifers depends, among other factors, on the properties of the compost and the geological material involved in the process.

Based on the above, this research aims to conduct a qualitative analysis of water quality parameters from six Monitoring Wells (MW) in a solid waste disposal area and public supply wells in the northwest region of the State of Rio Grande do Sul. This analysis was carried out through a historical series of concentrations of 12 chemical elements.

2. METHODOLOGY

2.1. Characterization of the study área

The study area is a landfill located in southern Brazil, close to the Rio Grande do Sul and Santa Catarina border. Concerning hydrography, it belongs to the Hydrographic Region of Uruguay (U) in the Várzea River Hydrographic Basin (U - 100), according to SEMA (2004). Regarding climate, it has an annual average of 1900 mm (Sotério et al., 2005; ABNT, 1997b) well distributed throughout the year, where the climate is of the Cfa type (humid subtropical) as described by Moreno (1961).

Regarding geological aspects, CPRM (2006) describes that the Serra Geral Formation (FSG), Fácies Paranapanema, is present in the region under study. According to the author, this formation is constituted by slim granular basaltic flows, melanocratic, containing vesicular horizons, thickly filled with quartz (amethyst), zeolites, carbonates, celadon native copper, and barite. In geological/geomorphological terms, it belongs to the Volcanic Province of the Paraná Basin (ROSS, 1985).

About hydrogeology, Machado and Freitas (2005) say that the study area is part of the Serra Geral I Aquifer System (SASG 1). According to the authors, this hydrostratigraphic unit is delimited by Soledade, Tupanciretã, Santo Antônio das Missões, Santa Rosa, Lieutenant Portela, Nonoai, Erechim, and Passo Fundo, and consists mainly of basaltic, amygdaloid, and fractured lithologies, capped by thick reddish soil. The local soil was classified by Borba (2016), following that proposed by EMBRAPA (2018), as a DYSTROPHIC RED LATOSOL (LVdf), with high clay contents (average values of 86%). In a previous study carried out in the area, the soil had a thickness ranging from 3.70 to 7.5 m until it found an impenetrable horizon to the equipment used for drilling (DARIVA AMBIENTAL, 2006; BORBA, 2016).

The unit, object of this study, receives about 1,700 tons of urban solid waste monthly from 31 municipalities in the region.

It also carries out the sorting, composting, and environmentally appropriate final disposal of the tailings. In the sorting process, around 16 % of the amount received is recovered, 272 tons monthly. The remainder is disposed of in the tailings disposal cells.

2.2. Environmental Monitoring System

Regarding the environmental monitoring required for the activity, there are six WM, called WM01 to WM06 (Figure 1), and WM01 is located outside the landfill area (upstream of the project) and is considered as a control or blank point. Table 1 presents its constructive information. For constructive reasons, WM 06 only gave some water samples. WM 04 was buried in 2011 due to a landslide in the upper area of the land. Thus, these wells are not monitored during the analyzed period.

To estimate the regional water table, including the study area, the values described by Borba (2016) were used from the interpolation by the inverse squared distance method of 98 water level information from tube wells located in neighboring municipalities. Using the CPRM database, the estimated value for the site is between 80.46 and 103.77 m.

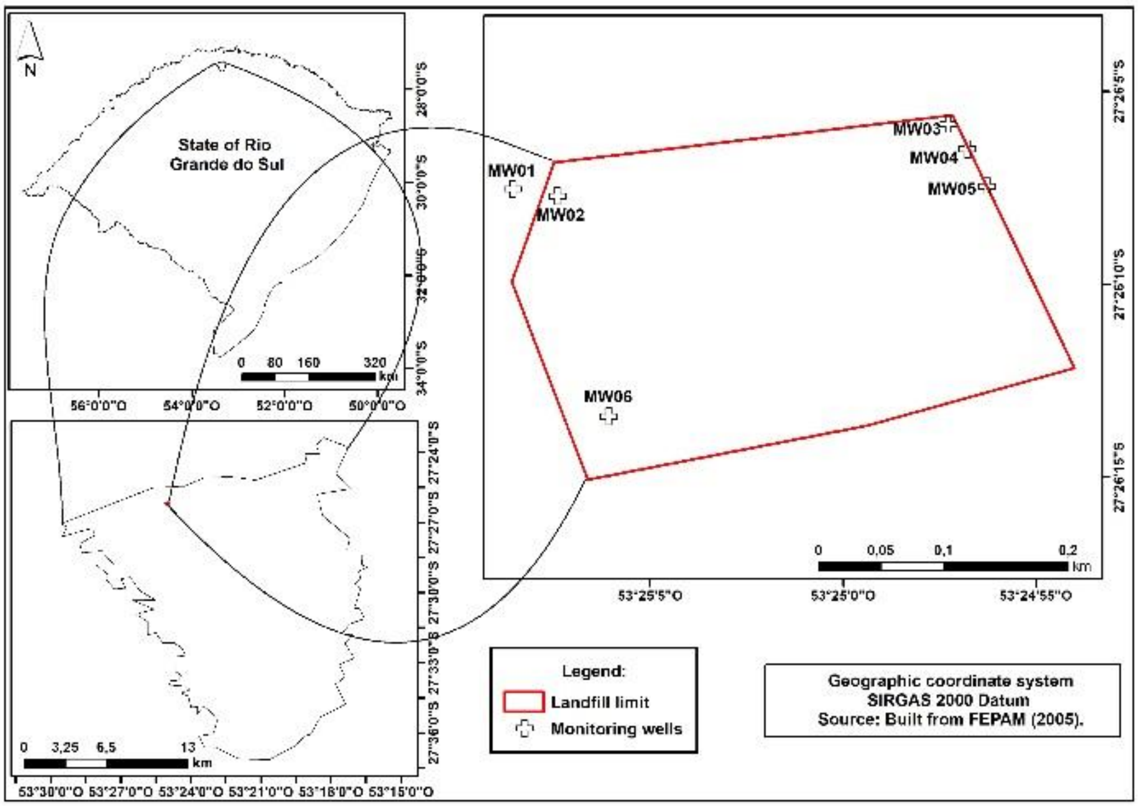

Figure 1 - Location monitoring wells. Source: Built from FEPAM (2005).

In addition, underground water is monitored in a supply well located about 500 m away from the landfill (upstream of the project). It should be noted that this wall was built outside the standards proposed by NBR 12.244/1992 (ABNT, 1992), mainly due to the absence of fencing, sanitary seal, faucet, and chlorination system. It should be noted that there are buildings close to the supply well to influence its water quality.

Table 1 - Constructive information of the six WM located in the study area.

WM	Topographic elevation (m)	Depth (m)**	Water level (m)***
01	537,00	5,30	0,60
02	540,00	4,20	0,25
03	528,00	3,70	0,20
04*	529,00	7,50	0,00
05	529,00	4,50	0,10
06	546,39	4,50	0,10

** Buried in 2011. ** Depth until finding an impenetrable horizon to the equipment used in drilling; *** Indicates water level when drilling. It is believed to have occurred in the rainy season or after heavy rains, marked very high. The PM03 measured with the aid of a soloist TLC probe had a depth of 4.60 m. PM04 had been without readings since 2011, and PM06 had only some initial tasks in 2007, and it was impossible to carry out collections from that period onwards.*

Groundwater quality monitoring is carried out quarterly by a service provider, WM, and the supply well. The packages are received, the samples collected, and sent for analysis at all points of interest, totaling an average of four analyzes per year. However, this amount depends on the water table level in the period, and at some time of the year, the well may not have water for collection. Table 2 shows the total supply for each analysis point and the start and end period. Table 3 shows the parameters analyzed, in addition to the methodology used.

Table 2 - Analysis points and total samples. Source: Built from monitoring reports

Analysis point	Analyzed period (Month/year)	Total samples in the period
Supply	05/2010 a 08/2017	18
WM01	10/2007 a 04/2018	22
WM02	10/2007 a 12/2015	6
WM03	10/2007 a 04/2018	18
WM04	10/2007 a 07/2011	6
WM05	10/2007 a 04/2015	7
WM06	10/2007	1

Table 3 - Water quality parameters monitored in PM and the supply well from 2007 to 2018. Source: Adapted from Brazil (2021) and Monitoring reports.

Parameter	Unit	Methodology	L.D.*
Alkalinity	mg $CaCO_3.L^{-1}$	SMEWW 22ª, Methodology nº 2320 “B”	1,00
Chlorides	mg $Cl^{-}.L^{-1}$	SMEWW 22ª, Methodology nº 4500 Cl “B”	0,50
thermotolerant coliforms	NMP**/100 mL	SMEWW 22ª, Methodology nº 9221 E	1,8 x 10^1
total coliforms	NMP/100 mL	SMEWW 22ª, Methodology nº 9223 B ***	1,8 x 10^1
Electric conductivity	$\mu S.cm^{-1}$	SMEWW 22ª, Methodology o nº 2510 “B”	0,00
BOD	mg $O_2.L^{-1}$	SMEWW 22ª, Methodology nº 5210 E	1,00
COD	mg $O_2.L^{-1}$	SMEWW 22ª, Methodology nº 5220 “D”	5,00
Nitrates	mg N-$NO_3.L^{-1}$	ABNT NBR 12.620	0,01
pH	-	SMEWW 22ª, Methodology nº 4500 - H^+ B	0,01
Total Dissolved Solids	$mg.L^{-1}$	SMEWW 22ª	-
Total solids	$mg.L^{-1}$	SMEWW 22ª, Methodology nº 2540 B	2,00
Sulfates	$mg.L^{-1}$	SMEWW 22ª, Methodology nº 4500 - SO_4^{-2} E	1,00

** Limit of Detection of the analyzed method, ** Most Probable Number, *** Standard Methods for examining Water and Wastewater.*

Rainfall information for crossing with water quality data was obtained from the National Institute of Meteorology (Inmet) website for the municipality of Frederico Westphalen - RS, automatic station code A854. The period analyzed was from December 2007 to April 2018, where precipitation values from 5 days before water collection were accumulated, as Borba (2016) described.

2.3. Statistical Analysis System

Statistical tests were applied on the mean values of the well water quality variables, in addition to the WM constructive parameters. In this way, these were submitted to assumptions, aiming to identify discrepant observations. The matrix was introduced to the Euclidean algorithm to build the distances between the variables measured in this study.

Afterward, this matrix was used to proceed with the relative contributions of the variables by the method of Sigh (1981) to expose and express which and how much each variable contributes to differentiate the treatments, as well as the optimized methodology of Tocher (CRUZ, 2006) to define homogeneous treatment groups for all measured variables, and to maximize heterogeneity between groups.

To graphically demonstrate the multivariate distances and contrasts of the treatments, the distance matrix was subjected to the Unweighted Pair-Group Method by Arithmetic Means (UPGMA) grouping. Dendrograms were constructed, as well as the principles of component methodology were applied to represent the total variability of the experiment in an X, Y, and Z Cartesian plane, making it possible to understand which treatment sources were similar multivariate. Statistical analyzes were performed using Genes (CRUZ, 2006), Statistical Analysis System (SAS, 1997), and Sigma Plot software.

The tested applications, in particular, were due to the characteristics of the information. Because it is information without repetition and collections in different periods, making it impossible to use conventional statistical tests. For this, we are competent, tests and methodologies that best fit the characteristics of the database.

With the application of the methods highlighted above, it is sought to assess whether the regulations involving small landfills protect the physical environment, even though this is a clayey substrate with low permeability and a deep water table, with values greater than 80 m.

3. RESULTS AND DISCUSSION

Monitoring water quality has as main objectives the control, diagnosis, and prognosis of the risk of contamination (MESTRINHO, 2008). Thus, it is possible to identify possible changes in the natural quality of the environment. In the area under study, underground water monitoring is carried out by a service provider, as requested by the competent environmental agency.

Next, the results corresponding to the parameters that have the Maximum Allowable Value (MAV) for current legislation will be illustrated (BRASIL, 2021), according to the predominant use for human supply, which is its principal use. In this area, monitoring between 2007 and 2015 has already been described by Borba (2016). Thus, in this survey, monitoring was expanded until 2018, encompassing another three years in the series of quarterly frequency information, identifying possible anomalies throughout the period. It should be noted that well WM04 has information only until 2011 and WM06 only for 2007.

Concerning microbiological water quality parameters, Ordinance Gm/MS N. 888 (BRASIL, 2021) considers the absence of 100 mL for total and thermotolerant coliforms as a drink. For water supply, 18 analyses were carried out (2010 to 2018); they were only within the MAV for total coliforms and one for thermotolerant.

In WM01, 22 were lost between October 2007 and April 2018, two of which were within the MAV for total coliforms and six for thermotolerance, altering the natural quality.

In WM02 (in the sixth between October 2007 and December 2015), two agreed with the MAV for both parameters. It should be noted that WM02 is located close to the septic tank, so that it may suffer some interference in quality parameters. In WM03, on 18 between October 2007 and April 2018, two dissipated in 100 mL for total coliforms and six for thermotolerant.

In six WM04 samples between October 2007 and July 2011, only one was absent in 100 mL for total coliforms and two for thermotolerant. In WM05, between October 2007 and December 2015, and in WM06, in October 2007, only one sample was absent for both parameters in seven collections (WM05) and one collection (WM06).

Thus, the microbiological parameters of water quality showed concentrations in disagreement with Brazil established (2021) in most collections. This would indicate that this water is unfit for human consumption since even the supply water in some samples showed total coliforms. This suggests the presence of pathogenic organisms, in the case of the supply well, maybe due to the irregularity of its construction, such as the absence of a sanitary seal, according to NBR 12.212/2017 (ABNT, 2017) and 12.244/2006 (ABNT, 2006), being outside the constructive norms. This procedure aims to protect the natural quality and protect the public health of users. In addition, it may be under anthropogenic interference (septic/rudimentary pits) located nearby.

About physical and chemical parameters, concentrations were random in all analyzed WM. In the supply water and WM02, only the nitrate parameter was above the MAV established by the current legislation (10 $mg.L^{-1}$) in one sample. In WM01, the parameters chloride, nitrate, and TDS presented concentrations above the established MAV (250, 10, and 1,000 $mg.L^{-1}$, respectively). In the case of PM03, the parameters Nitrate, Sulfate, and TDS were above the MAV. WM04, 05, and 06 did not show concentrations above the MAV for the parameters mentioned above.

Santos (2008) says that nitrate concentrations above 5 $mg.L^{-1}$ may indicate contamination by human actions, one of which is waste disposal. The author also states that these by-products from the decomposition of MSW are rich in nitrogen and decompose into nitrates in the presence of oxygen. In this sense, the high concentrations of organic matter in MSW release CO^2 in its decomposition.

Concerning chloride, Santos (2008) states that this parameter is naturally present in groundwater at concentrations below 100 $mg.L^{-1}$. The author also says that chloride is an excellent indicator of contamination by dumps and landfills. This is mainly due to the characteristic of the material generated by these activities, and the fact that it is stable in solution, that is, it hardly precipitates, where, from its high solubility and the slow movement of groundwater, leading to increased concentrations towards to the underground flow (SANTOS, 2008). Davis and Mastem (2016) say that the more soluble the material, the greater its probability of migrating vertically through the geological layers until reaching the aquifer, at the vadose zone interface to the aquifer.

In general, it was possible to identify fluctuations in the concentrations of the elements analyzed throughout the period (2007 to 2018), which may be associated with forming a non-continuous temporary suspended aquifer. Significant anomalies were identified in WM03 after the year 2013 mainly. It was impossible to determine the likely cause of this oscillation, and it is assumed. With the increase of residues in the cell, there was a more excellent percolation of material through the soil, altering its quality. The most likely hypothesis of the oscillation of water quality values may be related to forming a non-continuous temporary suspended aquifer.

When comparing the results of water quality analysis for the use of human supply concerning all WMs with CONAMA Resolution N. 396/2008 (BRAZIL, 2008), changes were identified in all analyzed parameters. The period from August 2015 to April 2018, as shown in Table 4, indicates the maximum values obtained for each element in the analyzed period. An increase in the concentrations of chloride (WM01), nitrate (WM01 and WM03), TDS (PM03), and also the presence of thermotolerant coliforms (supply water) was noticed. It indicates a clear anthropogenic contribution to these parameters. The other parameters did not show changes when compared to the years 2007 to 2015. Since, in the area of influence of WM01, there are crops of wheat, soybeans, and corn, and that management of these areas uses NPK-based fertilizers or fertigation with animal waste, it is believed that most concentrations of the elements nitrate and chloride can be derived from this activity.

Table 4 - Comparison of water quality parameters with CONAMA Resolution 396/2008 (BRAZIL, 2008) for 2007 to 2018. Source: Built from and monitoring reports.

	Analyzed Parameters (Concentrations)				
	mg.L^{-1}				NMP/100 mL
MAV*	**Chloride**	**Nitrate**	**STD**	**Sulfate**	**Thermotolerant coliforms**
	250,00	**10,00**	**1.000,00**	**250,00**	**Absence in 100 mL**
Supl.	91.90	50.79 **	140.00	5.00	Presence **
WM 01	424.40**	68.56 **	1,630.00**	25.00	Presence **
WM 02	137.70	18.78 **	870.00	49.00	Presence **
WM 03	196.60	31.79 **	1,581.00**	1,590.00**	Presence **
WM 04	37.10	6.61	122.00	1.77	Presence **
WM 05	80.50	5,820	334.00	10.00	Presence **
WM 06	10.40	-	-	-	Absence

***Adapted from Brazil (2008) and ** Concentration above the MAV (Brazil, 2008).*

Table 5 shows the Pearson correlation matrix for the analyzed variables as can be seen from the classification proposed by Dancey and Reidy (2013), where p values are labeled as Poor correlation (Values between 0.10 and 0.30), moderate (0.40 and 0.60), and strong (0.7 to 1.0). The parameters chloride (0.65) and COD (0.69) showed a low correlation with alkalinity. We verified the same between the parameters nitrate (0.49), BOD (0.41), and COD (0.49) with EC, total solids, and COD (0.57) and between TDS with the nitrate parameter (0.55).

Precipitation also had a low correlation with pH (0.48), not indicating dilution. A strong correlation was found between alkalinity and the variables EC (0.74), COD (0.74), and TDS (0.81). The same occurred between STD with chloride (0.92) and EC (0.89). Based on this, it can be indicated that the accumulated precipitation of 5 days before collections did not influence the quality parameters, except for the pH values. This may represent that the water quality parameters are more related to the soil solution and not to the precipitation that hits the ground in the surface layers, with the background showing clay values above 86 % (Borba, 2016).

Table 6 - Correlation matrix between water quality parameters and precipitation at the 5 % level. Source: Prepared in Action.

Parameter	Alk[1].	Chl.[2]	EC[3]	BOD[4]	COD[5]	Nitr.[6]	pH[7]	Tot. S..[8]	TDS[9]	Sulf.[10]	Prec.[11]
Alk.	1.00										
Chl.	0.65	1.00									
EC	0.74*	0.85*	1.00								
BOD	0.74*	0.37	0.49*	1.00							
COD	0.69*	0.30	0.41*	0.81*	1.00						
Nitr.	0.01	0.67*	0.49*	-0.18	-0.23	1.00					
pH	0.39	0.20	0.33	0.16	0.05	-0.03	1.00				
Tot. S.	-0.05	-0.11	-0.15	0.23	0.57*	-0.10	-0.21	1.00			
TDS	0.81*	0.92*	0.89*	0.50*	0.36	0.55*	0.31	-0.20	1.00		
Sulf.	0.30	0.22	0.20	0.04	0.28	-0.14	0.16	0.08	0.18	1.00	
Prec.	0.06	-0.09	0.08	-0.19	-0.29	0.04	0.48*	-0.22	0.11	-0.13	1.00

**Significant correlations with $p<0.05$; N=24; [1]Alkalinity, [2]Chlorides, [3]Electrical Conductivity, [4]Biochemical Oxygen Demand, [5]Chemical Oxygen Demand, [6]Nitrogen, [7]Hydrogeniomic Potential, [8]Total Solids, [9]Total Dissolved Solids, [10]Sulfate and [11]Precipitation.*

For a more specific analysis between the variables related to water quality and the construction parameters of the wells, the method of Singh (1981) was used. It was possible to notice that the microbiological parameters of water quality (thermotolerant and total coliforms) were the ones that most influenced the variability of the data collected, with 35.28 % and 20.91 %, respectively, indicating a change in natural quality. These parameters also showed, in most samples, concentrations in disagreement with current legislation (BRAZIL, 2021). Thus, Table 6 shows the relative contribution of the 12 water quality parameters evaluated in the six PM and the supply well.

Table 7 shows the relative contribution of the variables analyzed between the six WM and the supply well. It was possible to notice that PM2 (16.75 %) and WM03 (15.94 %) were the ones that most contributed to the variability of the variables. This is possibly related to the high concentrations of variables at these points. Thus, these wells were the ones that most contributed to differentiation, regardless of the quality characteristic of the analyzed water. Seeking to identify which of these variables showed homogeneous behavior among themselves, that is, the formation of groups, the Tocher method was applied (CRUZ, 2006), as shown in Table 7.

Table 6 - Relative contribution of 12 water quality parameters evaluated at six WM and in the supply well. Source: Author (2019).

Quality Parameter	Relative Contribution (%)
Thermotolerant coliforms[1]	35.28
Total coliforms[2]	20.91
electrical conductivity[3]	6.30
Alkalinity[4]	5.98
pH[5]	5.39
TDS[6]	5.38
COD[7]	5.00
Total solids[8]	4.35
Chlorides [9]	3.94
Nitrates[10]	3.27
BOD[11]	2.40
Sulphates[12]	1.80
Total	**100.00**

[1]Thermotolerant coliform; [2]Total coliforms; [3]Electrical conductivity; [4]Alkalinity; [5]Hydrogenionic potential; [6]Total dissolved solids; [7]Chemical oxygen demand; [8]Total solids; [9]Chlorides; [10]Nitrate; [11]Chemical demand for oxygen and [12]Sulfate.

Analyzing Table 8, it is possible to notice the presence of three large groups, which have characteristics that are homogeneous among themselves and heterogeneous among groups (CRUZ et al., 2012). The supply well, the WM01, the WM05, and the WM06 are the most homogeneous. They had the most similar characteristics (pH variables, fecal coliforms, and thermotolerant). These wells are located at higher topographic elevations. Thus, they suffer less interference from the activity when related to the relief.

The same occurred between WM02 and WM03 (nitrate, pH, fecal coliforms, and thermotolerant parameters). WM04 was the most heterogeneous among the seven analyzed, indicating that it does not have similar characteristics.

It should be noted that this well was buried in 2011, so it does not have complete monitoring. A better visualization can be seen in Figures 2 (A) and (B), illustrating the dissimilarity and principal components, respectively. The application of the main features sought to explain the variability of 70.66 % of the overall variation, where the supply variables (Supply), WM01, 05, and 06 presented more significant similarity between the analyzed variables, whereas WM04 showed less similarity between the variables. It may be related to the variability of the concentrations of the chemical variables of the water in the well in the period analyzed, as, in general, it was the one with the lowest concentration values.

Table 7 - Relative contribution between PM and the supply. Source: Author (2019).

Variables	Relative contribution (%)
WM02[1]	16.75
WM03[2]	15.94
WM04[3]	14.32
WM06[4]	14.14
WM05[5]	13.13
WM01[6]	12.89
Supply[7]	12.82
Total	**100.00**

[1]Monitoring well 02; [2]Monitoring well 03; [3]Monitoring well 04; [4]Monitoring well 06; [5]Monitoring well05; [6]Monitoring well 01; [7]Supply.

Table 8 - Application of the Tocher method for grouping variables related to WM and the supply well. Source: Author (2019).

Groups	Individuals			
1	Supply	WM01	WM05	WM06
2	WM02	WM03		
3	WM04			

Thus, it can be identified that the microbiological parameters most influenced the other water quality parameters. In relation to wel monitoring, WM02 and 03 were the ones that most contributed to the diversity of variables.

Concerning the constructive parameters of the wells, a series of variables were considered (Table 9), seeking to identify which would be the most important. These variables sought to present the relationship of characteristics involving the terrain and the location of the wells. It should be noted that the information referring to WM04 and WM06 was not taken into account since campaigns were not carried out to monitor the water level of these wells.

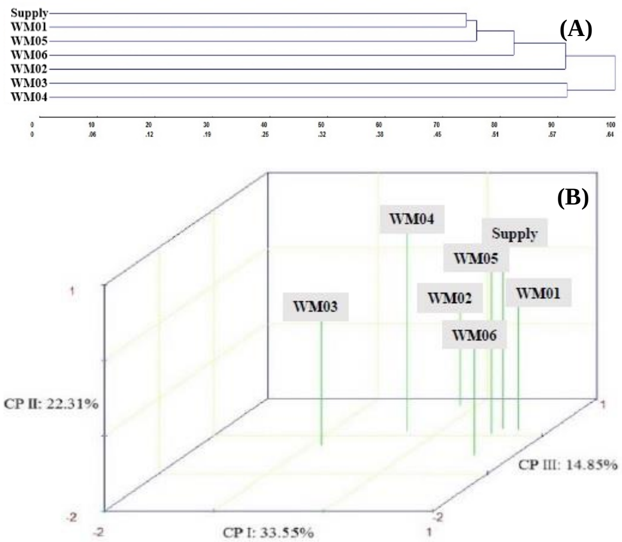

Figure 2 - Dissimilarity (A) and principal components (B) between the analyzed variables. Source: Author (2019).

Table 9 - Construction parameters of the WM in operation. Source: Author (2019).

Well	Quota ground (m)	Depth (m)	Distance of the cell (m)	Water level (m)
WM01	537.00	5.3	275	2.89
WM02	540.00	4.2	212	3.85
WM03	528.00	3.7	138	3.09
WM05	529.00	4.5	184	3.61

Table 10 shows the relative contribution of the constructive variables. As can be seen, the variables depth (28.33 %) and water level (26.17 %) were the ones that most contributed to the diversity of the data. That is, they represent great importance in the distribution of the variables. The average water level values were described by Borba (2016) between April 2015 and March 2016 for the condition of a temporarily suspended aquifer. This type of aquifer presents fluctuations in the water level in response to periods of more significant rainfall. However, its location in the landscape did not show a direct correlation, as mentioned above. Table 11 presents the grouping of variables according to the Tocher test (CRUZ, 2006). It was possible to identify two large groups, represented by WM 02, 05, and 01 and another group represented by WM03. This indicates that WM 01, 02, and 05 have similar conditions, whereas WM03 has more heterogeneous characteristics among the WM analyzed.

Table 10 - Relative contribution of the four PM constructive variables. Source: Author (2019).

Variables	Relative contribution (%)
Depth	28.33
Water level	26.17
Distance to the cell	23.02
Quota ground	22.46
Total	**100.00**

Table 11 - Application of Tocher's method for grouping variables related to construction parameters. Source: Author (2019).

Group	Individuals		
1	WM02	WM05	WM01
2	WM03		

In Figure 3A, the dissimilarity and the main components are shown. As can be seen, PM02, 05, and 01 have more remarkable similarities through the variables depth and static level. In the second group, PM03 showed a more significant dissimilarity of information in all variables.

The analysis from the principal components (Figure 3B) allowed us to explain 96.30 % of the general variation of the variables. As shown, the WM02 and the WM05 showed similar trends in the terrain elevation, depth, and static level variables.

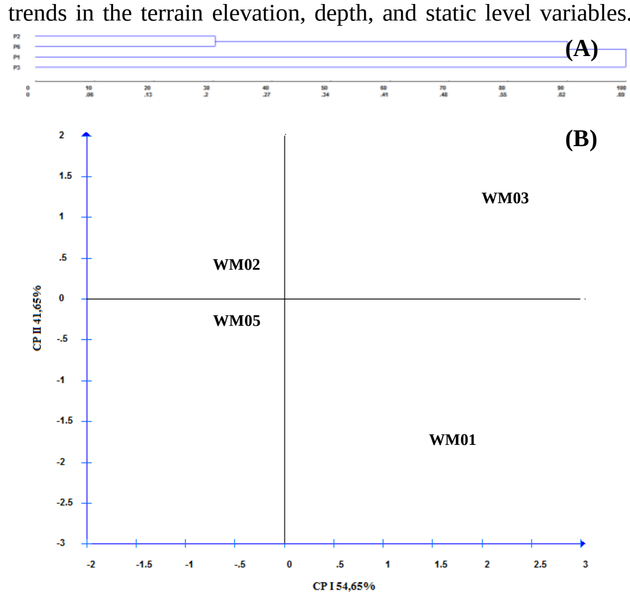

Figura 3 - Dissimilaridad (A) e componentes principais (B) dos PM analisados. Fonte: Autor (2019).

4. FINAL CONSIDERATIONS

The analysis of the water quality parameters of the monitoring wells allowed the identification of changes in concentrations, mainly coliforms (total and thermotolerant), chlorides, nitrates, and sulfates. Only the pH showed a positive correlation at the level of 5 % with precipitation, indicating that this variable is not related to the concentrations of the others.

The microbiological variables of water quality (total and thermotolerant coliforms) were the ones that most contributed to the variability of information. Furthermore, the variables were grouped into three large groups with similar characteristics. Regarding the constructive parameters between the monitoring wells, only the WM03 was isolated, indicating that it has individual features, which were also verified in groundwater quality monitoring, as it was the one with tremendous fluctuations. Thus, this research proved to be efficient, serving as a basis, for example, for the installation of new monitoring wells, as they indicated, based on information from the construction parameters, which of the active wells have characteristics that match the reality of the location. In addition, it allowed analyzing the variability of chemical elements from the analyzed period, serving as a basis for the decision-making process. Thus, it was possible to identify that the changes in the parameters were consistent with the underground flow since the active well with the lowest topographical elevation was the one with the most significant variability in the water quality variables.

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