Environmental Diagnosis of the Unconfined Aquifer in the Coastal Region of Northeast Brazil

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Abstract

Groundwater is a large percentage of sweet easily accessible water and is often the only option for drinking water supply. In general, it possesses better quality due to interactions with the ground during percolation. In urban areas, however, various activities compromise its quality and demand, such as installation of black tanks, wastewater without treatment or with inadequate treatment, improper disposal of solid waste, waterproofing recharge areas, storage of dangerous products in underground or air tanks without basin containment, among others. The aim of this study was to evaluate the contamination of the unconfined aquifer in the North Zone of Aracaju, SE, through the analysis of physical, chemical and biological parameters of water samples from shallow wells, relating to potential sources of contamination, evaluating the effects of seasonality and comparing them to the limits of potability of Decree No. 2,914 / 2011 of the Ministry of Health, the results show that all samples were unfit for human consumption for at least one of the 13 analyzed parameters, with the most significant change in the dry season.

Keywords: groundwater; water quality; potability standards

1. Introduction

Groundwater generally has good quality for human consumption, requiring less treatment costs than surface water, which makes it more accessible to the public (LAVOIE et al, 2015). Although a significant portion of Brazilian municipalities use groundwater to supply, there are few studies about the resource, its water potential and quality, and most of these are focused on specific issues in the characterization of contaminated sites (ANA, 2007; IBGE, 2010).

According to Araujo (2009), regions with sandy soil and sedimentary rocks, such as Aracaju, are potential suppliers of underground water by porosity and high permeability of this formation, allowing exploration of significant flows.

By being more superficial, the unconfined aquifer is the most exploited by population, and is highly susceptible to contamination (E SILVA ARAUJO, 2003; LIBANIO, 2005; Silva et al, 2014). The contamination of these aquifers is reflected in an important public health problem, since the human consumption of drinking water is one of the biggest ways to prevent disease (E ARAUJO SILVA, 2003).

According to data published by IBGE (2010), only 26 municipalities in Sergipe have sewage, and, out of these, only 07 perform some kind of treatment. The lack of an efficient environmental sanitation system requires the use of tank-filter-sink, contributing to groundwater contamination, naturally high in sandy soils (FRANCE 2011). Garcia et al (2011) identified contaminated areas in the greater Aracaju associated with domestic and industrial effluents untreated, from trace metals analysis in sediments of rivers, potential contamination of the aquifer.

CETESB reported in 2014 that 5,148 contaminated areas, of which 74.3% related to gas stations and 16.74% industries. Fuels have compounds such as Benzene, Toluene, Ethylbenzene and Xylene, which have high toxicity and carcinogenic potential, directly affecting the central nervous system. Once present in the aquifer, decontamination procedures are needed, usually with high implementation costs.

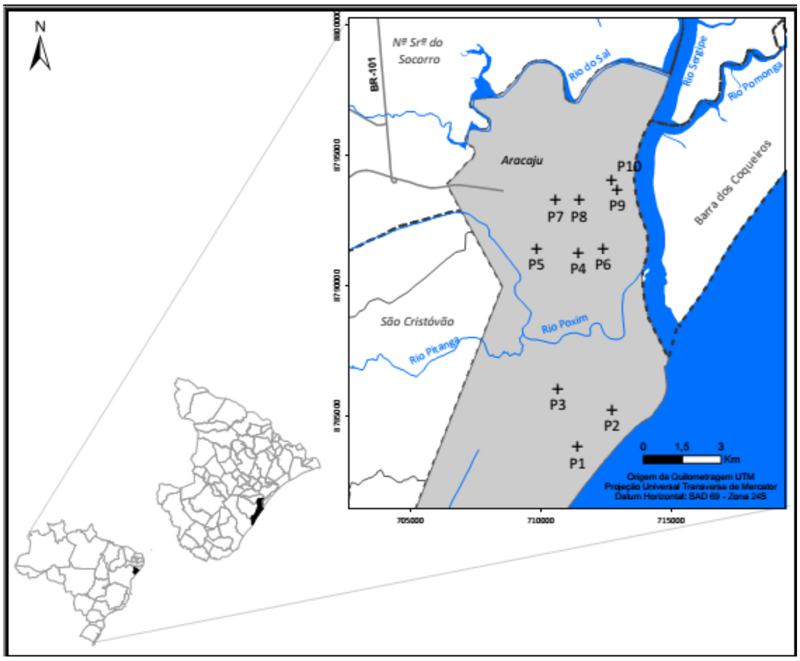
Because of the susceptibility to so many potential sources of pollution, analysis of physical and chemical parameters is not only important to assess water quality in relation to legislation, but also to evaluate their behavior with the contamination, such as its potential for degradation.

In this context, the aim of this study is to evaluate the contamination of the unconfined aquifer in the North Zone of the municipality of Aracaju / SE, through the analysis of physical, chemical and biological parameters in water samples from shallow wells, relating to human activities and potential sources contamination, comparing the results to the limits of potability of Decree No. 2,914 / 2011 of the Ministry of Health.

2. Materials and methods

2.1. Study Area

The study area is located the north of the city of Aracaju and in the east of Sergipe, being part of the basin of the Sergipe and Vaza Barris Rivers (Figure 1). Data published by the IBGE (2016), the estimated population of Aracaju in 2015 was of 632,744 inhabitants, the most populous city in the state. The climate is megathermal sub-humid, with an average monthly temperatures ranging from 24.65 ° C to 27.32 ° C, rainy season between April and August, and the dry season between September and March. The predominant aquifer is the granular one, formed by sedimentary rocks of the surface formations of the Cenozoic Era, with good storage capacity and water supply due to primary porosity and high permeability of sandy soils (PINTO et al, 2000; ARAUJO, 2009; SERGIPE, 2012; JESUS, 2015 INMET, 2016).



Source: Sergipe (2012).

Figure 1. Study area and location of sampling points.

2.2. Methodology

For this work, 10 shallows monitoring wells (up to 8 m deep) were selected to collect, all of them already existing, manually drilled with auger and located in the unconfined aquifer in the North Zone of Aracaju. The sample size was established at the cost of analysis and the twells available for collection. The samplings were carried out in May (rainy season) and in November and December 2015 (dry season), evaluating the seasonal effect for the environmental parameters: pH, temperature, electrical conductivity, total dissolved solids, turbidity, color, dissolved oxygen, chlorine, free residual nutrients (nitrate, nitrite, ammonia and phosphate), total coliforms, fecal coliforms.

Samples were taken with a sampler bailer manual of double valve, disposable, and immediately transferred to containers appropriate for each analysis, properly identified with tags, and preserved in ice. The valve in the bailer allows the sample to be transferred to sample containers with less loss of volatiles compounds (ASTM, 2010). The collection forms were filled with the data on the collected sample (place, date, sample number, time condition), and the static level of the well.

The preservation of the samples and analysis of the parameters followed the analytic method described in Standard Methods for the Examination of Water and Wastewater (APHA, 1998). Analyses were performed at the Environmental Analytical Chemistry Laboratory - LQA - in the Federal University of Sergipe, except total and fecal coliforms, which were analyzed at the Technological Institute and Research of the State of Sergipe - ITPS.

The results were analyzed for dry and rainy season, and when appropriate, compared to the maximum permissible values recommended by Decree No. 2,914 / 2011 of the Ministry of Health, and the CONAMA

420/2009 in order to characterize the quality of the underground water for potable purposes.

3. Results and discussion

The results obtained in this study were tabulated and analyzed for physico-chemical parameters mentioned above.

3.1. Temperature and pH

The temperature of the samples ranged from 29.4 to 35 °C during the rainy season and from 32.1 to 35.8 °C in the dry season. The pH is a function of the carbon dioxide dissolved in water, and in underground water usually varies between 5.5 and 8.5 (SANTOS, 2000). The pH values ranged from 6.07 to 7.16 in the rainy season and from 4.10 to 7.29 in the dry season. Ordinance No. 2,914 / 2011 of the Ministry of Health does not provide a value for human consumption, but recommends pH between 6.0 and 9.5 in the distribution system. For this group, only the sample of P10 (pH = 4.1), dry period, would be outside the box and require a pH correction.

3.2. Electrical Conductivity (EC)

The electrical conductivity is the result of dissolved salts in the water, in the form of ions (SANTOS, 2000; LIBANIO, 2005). In the dry season, there was an increase of conductivity in all analyzed points. The values ranged from 119.7 to 1047.0 $\mu S.cm^{-1}$ in the rainy season, and from 578.0 to 4705.0 $\mu S.cm^{-1}$ in the dry season. This behavior, in general, is a consequence of higher dilution of compounds during the rainy season. Capp et al (2012) associated the high electrical conductivity values detected in four sample from shallow wells in the urban area of Anastacio / MS to the absence of an effective health system and public policies which performed an effective control of pollution sources (Table 1).

3.3. Total Dissolved Solids (TDS), Turbidity and Color

Following the same trend of conductivity, the total dissolved solids concentrations were higher in the dry season in all analyzed points, ranging from 59.9 to 522.0 mg L^{-1} in the dry season, and from 287.5 to 2,360.0 mg L^{-1} in the rainy season (Table 1). Out of the 10 points analyzed in the dry season, seven samples do not meet the potability standards of the Ministry of Health, which determines the maximum value of 1,000.0 mg L^{-1}.

Turbidity is an interference with the passage of the light in water as a result of suspended solids (SANTOS, 2000; LIBANIO, 2005). All samples in the two campaigns showed turbidity below 5 UT, thus meeting the potability standards. Color, in turn, is commonly the result of dissolved compounds, such as iron and manganese, and may be related to decomposition of organic matter or human influence (LIBANIO, 2005; BRAZIL, 2013). Of the points analyzed, only the P07 showed color values within the limit established by the decree of the Ministry of Health (under 15 uH or 15 mg L^{-1} Pt-Co) in the two campaigns analyzed, with values equal to 6.67 uH and 9.27 uH in the rainy and dry seasons, respectively (Table 1) and (Table 2).

Table 1. Physicochemical parameters analyzed in the groundwater samples for the rainy season.

Site	T	pH	EC	DTS	Turbidity	Color	DO
	°C	mg L^{-1}	µS cm^{-1}	mg L^{-1}	NTU	mg L^{-1} Pt-Co	mg L^{-1}
P01	34.7	7.14 ±0.13	957.00 ±34.69	485.00 ±18.19	25.40 ±12.49	27.59 ±1.49	0.21 ±0.05
P02	31.6	6.76 ±0.19	1,047.00 ±32.49	522.00 ±17.63	76.00 ±9.08	40.55 ±1.88	0
P03	33.0	6.53 ±0.27	283.00 ±35.52	142.00 ±15.08	49.00 ±9.00	41.84 ±0.98	0.83 ±0.09
P04	31.2	6.07 ±0.18	441.00 ±20.21	224.00 ±26.03	41.80 ±10.15	23.15 ±0.40	1.38 ±0.15
P05	31.4	6.07 ±0.19	241.00 ±27.45	121.00 ±11.39	26.70 ±3.15	37.77 ±1.24	0.83 ±0.14
P06	30.4	6.69 ±0.26	965.00 ±23.93	483.00 ±6.32	68.60 ±11.24	22.04 ±0.40	0.69 ±0.05
P07	29.4	7.16 ±0.19	158.30 ±57.49	79.70 ±31.58	17.90 ±5.35	6.67 ±0.99	2.76 ±0.13
P08	35.0	6.70 ±0.26	540.00 ±33.01	271.00 ±6.30	13.53 ±2.75	9.26 ±1.13	0.96 ±0.12
P09	30.4	7.06 ±0.21	119.70 ±36.47	59.90 ±18.76	18.22 ±5.58	12.59 ±0.85	2.62 ±0.07
P10	29.9	6.69 ±0.14	814.00 ±30.11	407.00 ±27.17	16.02 ±14.49	34.07 ±2.09	0.69 ±0.10

n.d. Not detected

3.4. Dissolved Oxygen (DO) and Free Residual Chlorine

Despite the concentration of dissolved oxygen in the water does not influence the potability, its review allows us to understand the system dynamics and is directly related to the degradation of some organic compounds. Most of the samples showed a concentration of dissolved oxygen lower or absent in the dry season, with the exception of P04, P05 and P06 points. The P02 point showed no dissolved oxygen in any of the campaigns made. It is possible that this absence is related to biodegradation of organic compounds derived from a recent contamination by domestic sewage, as evidenced by high ammonia levels identified.

Free residual chlorine was not detected in any of the studied points.

Table 2. Physicochemical parameters analyzed in the groundwater samples for the dry season.

Site	T	pH	EC	DTS	Turbidity	Color	DO
	°C	mg L^{-1}	µS cm^{-1}	mg L^{-1}	NTU	mg L^{-1} Pt-Co	mg L^{-1}
P01	34.5	6.80 ±0.16	3,080.00 ±6.73	1,550.00 ±27.66	71.40 ±6.25	66.13 ±0.32	n.d.
P02	32.6	6.80 ±0.12	3,590.00 ±25.40	1,790.00 ±29.68	66.80 ±10.42	60.92 ±1.50	n.d.
P03	34.3	7.09 ±0.31	2,205.00 ±12.44	1,095.00 ±11.29	38.00 ±6.73	138.77 ±1.44	n.d.
P04	33.0	6.32 ±0.16	2,950.00 ±40.33	1,475.00 ±19.06	12.34 ±6.81	61.52 ±1.29	1.65 ±0.15
P05	32.9	7.29 ±0.23	578.00 ±13.27	287.50 ±31.04	13.02 ±6.25	87.38 ±0.35	1.59 ±0.04
P06	32.1	6.74 ±0.17	4,705.00 ±15.69	2,360.00 ±29.85	58.80 ±4.79	45.07 ±1.63	3.72 ±0.10
P07	32.6	6.94 ±0.28	1,910.00 ±25.27	950.00 ±17.31	23.40 ±4.76	9.27 ±0.88	0.96 ±0.11
P08	34.5	6.98 ±0.17	2,650.00 ±10.16	1,330.00 ±18.88	20.40 ±7.50	27.40 ±2.12	0.41 ±0.03
P09	32.9	6.85 ±0.27	1,535.00 ±38.23	775.00 ±15.47	8.67 ±1.00	27.78 ±0.84	1.38 ±0.10
P10	35.8	4.10 ±0.14	4,360.00 ±42.93	2,175.00 ±12.48	56.40 ±5.14	98.38 ±0.97	n.d.

n.d. Not detected

3.5. Nutrients: Nitrate, Nitrite, Ammonia and Phosphate

The nutrients are represented by nitrogen and phosphorus compounds and are related in general to contamination by agricultural fertilizers and sewage. Among nitrogen compounds, nitrate is the most commonly found in groundwater once is the most stable form of dissolved nitrogen, and represents an earlier contamination, while higher concentrations of nitrite, for example, correspond to a recent contamination (SON, 2000; SANTOS, 2000).

Nitrate, Nitrite, Ammonia and Phosphate showed higher concentrations in the dry season, when there is less dilution of existing pollutants. Only 03 points had nitrate levels above the limit of 10 mg L^{-1} under Brazilian law for human consumption - P04, P06 and P08. The P06 and P08 points have rainwater drainage channels nearby, which the odor and appearance are clandestinely used to launch domestic sewage, and may influence those identified high concentrations. The P04 is located in a predominantly residential area, with marked vertical integration, and found levels must be related to contamination by black tanks, mainly of homes and older buildings.

As regarding to nitrite, the concentrations were below the legal limit (1 mg L^{-1}), and in three points were not detected concentrations in any of the campaigns (P01, P02 and P09), and in the points P05 and P07 were only detected in the dry season.

The six points analyzed showed ammonia values within the potability standards, below 1.5 mg L^{-1}. The remaining points went beyond, and the P02 more critical, with 26.54 and 32.04 mg L^{-1} in the rainy and dry seasons, respectively (Table 3) and (Table 4), indicative of a recent contamination by domestic sewage. The absence of dissolved oxygen at this point may be the result of oxidation and biodegradation processes of these compounds.

Table 3. Total concentration of nutrients in ground water in the rainy season.

Site	Nitrate mg L^{-1}	Nitrite mg L^{-1}	Ammonia mg L^{-1}	Phosphate mg L^{-1}
P01	2.624 ±0.204	n.d.	2.128 ±0.019	n.d
P02	3.034 ±0.119	n.d.	26.536 ±0.007	0.036 ±0.014
P03	8.092 ±0.133	0.044 ±0.008	0.595 ±0.008	n.d.
P04	36.244 ±0.196	0.026 ±0.003	0.585 ±0.015	0.991 ±0.021
P05	4.225 ±0.148	n.d.	0.758 ±0.012	0.091 ±0.012
P06	49.597 ±0.119	0.294 ±0.054	2.383 ±0.010	2.197 ±0.010
P07	5.309 ±0.192	n.d.	0.654 ±0.018	0.119 ±0.019
P08	32.483 ±0.100	0.396 ±0.083	0.393 ±0.010	3.309 ±0.018
P09	5.536 ±0.108	n.d.	0.669 ±0.021	0.102 ±0.012
P10	4.995 ±0.205	n.d.	6.071 ±0.011	0.029 ±0.018

n.d. Not detected

Phosphate has no maximum value defined by the legislation as it presents no risk to health. Their environmental relevance is due to be strongly related to the presence of detergents, fertilizers and sewage (SON, 2000; SANTOS, 2000). According to Santos (2000) and Silva et al (2014), concentrations above 1 mg L^{-1} are indicative of polluted water, which would be the case of the water collected from P01, P04, P06 and P08 points.

Table 4. Total concentration of nutrients in ground water in the dry season.

Site	Nitrate	Nitrite	Ammonia	Phosphate
	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}
P01	2.691 ±0.190	n.d.	2.220 ±0.010	1.086 ±0.019
P02	3.492 ±0.189	n.d.	32.044 ±0.018	0.038 ±0.21
P03	9.779 ±0.209	0.049 ±0.007	0.646 ±0.015	n.d.
P04	38.187 ±0.120	0.027 ±0.007	0.628 ±0.011	1.045 ±0.015
P05	5.154 ±0.170	0.0013 ±0.0009	0.893 ±0.014	0.110 ±0.020
P06	59.312 ±0.165	0.320 ±0.087	2.503 ±0.016	2.507 ±0.020
P07	5.851 ±0.206	0.023 ±0.005	0.721 ±0.014	0.130 ±0.015
P08	36.183 ±0.141	0.467 ±0.069	0.415 ±0.006	3.608 ±0.020
P09	6.522 ±0.099	n.d.	0.805 ±0.018	0.122 ±0.016
P10	5.961 ±0.195	0.093 ±0.006	6.929 ±0.006	0.033 ±0.014

n.d. Not detected

The increase in nutrient concentrations observed in P04, P05 and P06 points, associated with the increased concentrations of dissolved oxygen, indicates that local conditions do not favor the biodegradation of this compound.

3.6. Total and Fecal Coliforms

Microbiological analysis is an important tool for water quality control, because diseases such as cholera, typhoid, gastroenteritis, leptospirosis, diarrhea, among others, are borne pathogens present organisms in the stool, which reach groundwater by domestic sewage without treatment and disinfection (Garcia and ALVES, 2006). The determination of microbiological pattern is made by quantification of thermotolerant coliforms, used as indicators of pathogenic organisms, to be easier to detect and quantify, having longer life in water than bacterial intestinal pathogens, they do not multiply when out of the human intestine and are more resistant to disinfectants (BRAZIL, 2013).

The presence of total and fecal coliforms in all samples analyzed in the rainy season was detected. In the dry period, total coliforms were detected in 7 of 10 points analyzed and fecal coliforms found in two points, P01 and P10. In the rainy season, the major input of water causes flooding of septic tanks and carries contaminants and pathogens in the environment in greater quantity than the natural percolation of tanks, which explains the higher concentration of these organisms in samples of the rainy season. According to Decree No. 2,914/11, total coliforms should be absent in 100ml sample, and regarding to the thermotolerant, it only mentions Escherichia coli, which is a more specific indicator of recent fecal contamination (BRAZIL, 2013). Thus, all points would be unfit for human consumption by at least one of the campaigns. Groundwater assessment studies of shallow wells have found similar results (Silva and Araujo, 2003; Silva et al, 2013; Silva et al, 2014).

Thus, the analysis of the quality of the unconfined aquifer for human consumption was made based on the maximum amounts permitted by potability of Decree No. 2,914/11, the Ministry of Health (BRAZIL, 2011). Among the 13 parameters analyzed in this study, 7 have maximum limits set by the said ordinance, and determine whether the water is very or not for this use. It was observed that all 10 points are considered suitable for human consumption to at least one potability parameters. A similar result was obtained by

Lamb et al (2011) analysis of 10 shallow wells used for domestic supply in the city of Macaé/RJ, identifying 9 points off the water potability standards, and therefore are also unfit for human consumption.

In number of parameters exceeded, the P01, P02 and P10 points presented the most critical results, as would be improper to 9, 10 and 5 parameters in the rainy season, and 10, 9 and 12 parameters in the dry season, respectively. The parameter which showed changes among the 20 samples analyzed were total coliforms, which was present in 17 samples (10 samples in the rainy season and 7 in the dry season). Fecal coliforms were also present in most samples, being detected in all samples of the rainy season and in two samples in the dry season, P01 and P10. Color was also representative, with values exceeded in 16 samples (7 in the dry season and 9 in the rainy season).

4. Conclusion

Aracaju has vulnerabilities which allow us to infer a poor quality of the unconfined aquifer, because besides the existence of the various impacts inherent to urban areas, the predominance of sandy soils provides conditions favorable for contamination. The results diagnosed that water is suitable for human consumption at all points analyzed for at least one parameter potability.

High levels of nitrogen and coliform were found, probably as a result of the use of black tanks or domestic wastewater treatment systems inadequate for the population. The domestic sewage is not done in all areas of the city, often requiring the implementation of alternative systems for the population.

Regarding seasonality, in 8 of the 13 parameters analyzed, the results were higher in the dry season, mainly related to higher dilution of compounds in the rainy season. As regards to the coliforms, however, the opposite occurred, the values were higher in the rainy season (highest number of contaminated samples), they reflect the flooding of tanks in that period, and the entrainment of pathogenic organisms.

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6. References

ANA Agência Nacional de Águas (2007). *Panorama do enquadramento dos corpos d'água do Brasil, e, Panorama da qualidade das águas subterrâneas no Brasil*. Agência Nacional de Águas/Superintendência de Planejamento de Recursos Hídricos, Cadernos de Recursos Hídricos, Brasília, ANA, SPR.

APHA American Public Health Association (1998). *Standard Methods for the Examination of Water and Wasterwater*. 20 ed. Washington, APHA.

ARAÚJO, H. M.; BEZERRA, G. S.; SOUZA, A. C. (2009). Hidrografia e hidrogeologia: qualidade e disponibilidade de água para abastecimento humano na bacia costeira do rio Sergipe. In: *Simpósio*

Brasileiro de Geografia Física Aplicada, 13., Anais eletrônicos, Viçosa, UFV. https://ri.ufs.br/bitstream/123456789/526/1/Hidrografia%20e%20hidrogeologia.pdf. Accessed 23 nov. 2014.

ASTM (2010). *Method D6699-01***:** *Standard practice for sampling liquids using bailers*. ASTM International, Pennsylvania.

Brasil (2013). *Manual prático de análise de água.* 4ª ed. Brasília, Fundação Nacional de Saúde.

BRASIL (2011). Ministério da Saúde. Portaria 2.914, de 12 de dezembro de 2011. Dispõe sobre os procedimentos de controle e de vigilância da qualidade da água para consumo humano e seu padrão de potabilidade. *Diário Oficial [da] República Federativa do Brasil*, Brasília, 14 dez. 2011, Seção V. p. 32.

CETESB Companhia Ambiental do Estado de São Paulo (2014). Texto explicativo: relação de áreas contaminadas no estado de São Paulo. Diretoria de Controle e Licenciamento Ambiental, CETESB, São Paulo. http://areascontaminadas.cetesb.sp.gov.br/wp-content/uploads/sites/45/2013/11/texto-explicativo1.pdf. Accessed 23 jan. 2016.

CONAMA Conselho Nacional de Meio Ambiente (2008). Resolução CONAMA Nº. 396, de 3 de abril de 2008. Dispõe sobre a classificação e diretrizes ambientais para o enquadramento das águas subterrâneas e dá outras providências. *Diário Oficial [da] República Federativa do Brasil,* Brasília, 7 abr. 2008, Seção 1, p. 64-68.

CONAMA Conselho Nacional de Meio Ambiente (2009). Resolução CONAMA Nº. 420, de 28 de dezembro de 2009. Dispõe sobre critérios e valores orientadores de qualidade do solo quanto à presença de substâncias químicas e estabelece diretrizes para o gerenciamento ambiental de áreas contaminadas por essas substâncias em decorrência de atividades antrópicas. *Diário Oficial [da] República Federativa do Brasil,* Brasília, 30 dez. 2009, p. 81-84.

Cordeiro, M. R.; Rodrigues, S. M.; de Souza, P. R. N.; Ferreira, M. I. P. (2011). Avaliação da contaminação de efluentes domésticos em poços sobre área de restinga. *Boletim do Observatório Ambiental Alberto Ribeiro Lamego*, v. 5, n. 1, p. 89-102.

CORSEUIL, H. X.; ALVAREZ, P. J. J. (1996). Natural bioremediation perspective for BTX-contaminated groundwater in Brazil: effect of ethanol. *Water Science and Technology*, v. 34, n. 7, p. 311-318.

FILHO, J. M. (2000). Contaminação das águas subterrâneas. In: Feitosa, F. A. C e FILHO, J. M (org.). *Hidrogeologia: conceitos e aplicações*. 2. Ed, Fortaleza, CPRM/REFO, LABHID-UFPE.

FRANÇA, S. L. A. (2011). Zona de expansão urbana de Aracaju: conflitos entre ocupação e condições ambientais. In: *Encontro Nacional da Anpur*, 14., Rio de Janeiro.

GARCIA, C. A. B.; PASSOS, E. A.; ALVES, J. P. H. (2011). Assessment of trace metals pollution in estuarine sediments using SEM-AVS and ERM–ERL predictions. *Environmental monitoring and assessment*, v. 181, n. 1-4, p. 385-397.

GARCIA, C. A. B.; ALVES, J. P. H. (2006). Qualidade da água. In: *Diagnóstico e avaliação da sub-bacia hidrográfica do rio Poxim*. Relatório Final, UFS/FAPESE, Aracaju.

INMET Instituto Nacional de Meteorologia (2016). Banco de Dados Meteorológicos para Ensino e Pesquisa. http://www.inmet.gov.br/projetos/rede/pesquisa/. Accessed 30 jan. 2016

IBGE Instituto Brasileiro de Geografia e Estatística (2016). Censo Demográfico 2010. Instituto Brasileiro de Geografia e Estatística. http://www.cidades.ibge.gov.br/xtras/perfil.php?lang=&codmun=280030. Accessed 24 jan. 2016.

IBGE Instituto Brasileiro de Geografia e Estatística (2010). Pesquisa nacional de saneamento básico - 2008. Instituto Brasileiro de Geografia e Estatística, Rio de Janeiro. http://biblioteca.ibge.gov.br/visualizacao/livros/liv45351.pdf. Accessed 24 jan. 2016.

JESUS, J. B. (2015). Estimativa do balanço hídrico climatológico e classificação climática pelo método de Thornthwaite e Mather para o município de Aracaju-SE. *Scientia Plena*, v. 11, n. 5.

LAVOIE, R.; Joerin, F.; Vansnick, J.C.; Rodriguez, M. J. (2015). Integrating groundwater into land planning: A risk assessment methodology. *Journal of Environmental Management*, v. 154, p. 358-371.

LIBÂNIO, M. (2005). *Fundamentos de qualidade e tratamento de água*. Campinas/SP, Editora Átomo.

PINTO, J. E. S. S.; SANTOS, F. V.; SOUSA, I. F. (2000). Variação Rítmica dos elementos climáticos em Aracaju,SE. Rio de Janeiro-RJ, Sociedade Brasileira de Meteorologia, p. 641-647. http://www.cbmet.com/cbm-files/12-54b288633434b1633436a1881aa85582.pdf. Accessed 20 mar. 2016.

SANTOS, A.C. (2000). Noções de hidroquímica. In: Feitosa, F. A. C e FILHO, J. M (org.). *Hidrogeologia: conceitos e aplicações*. 2. ed. Fortaleza, CPRM/REFO, LABHID-UFPE.

SERGIPE (2012). Secretaria de Estado do Planejamento e da Ciência e Tecnologia. Superintendência de Recursos Hídricos. Atlas digital sobre recursos hídricos. Aracaju, SEPLANTEC/SRH, CD-ROM.

SILVA, C. A.; STRAPAÇÃO, S.; YAMANAKA, E. H. U.; BALLÃO, C.; MONTEIRO, C. S. (2013). Potabilidade da água de poços rasos em uma comunidade tradicional, Curitiba-PR. *Revista Biociências*, Taubaté, v.19, p. 88-92.

SILVA, D. D.; Migliorini, R. B.; SILVA, E. C.; LIMA, Z. M.; MOURA, I; B. (2014). Falta de saneamento básico e as águas subterrâneas em aquífero freático: região do Bairro Pedra Noventa, Cuiabá (MT). *Eng Sanit Ambient,* v. 19, n. 1, p. 43-52.

SILVA, R. C. A.; ARAÚJO, T. M. (2003). Qualidade da água do manancial subterrâneo em áreas urbanas de Feira de Santana (BA). *Ciênc. saúde coletiva*, São Paulo, v. 8, n. 4.