REVISTA CAMINHOS DE GEOGRAFIA ISSN 1678-6343
http://www.seer.ufu.br/index.php/caminhosdegeografia/ DOI: https://doi.org/10.14393/RCG228457049

VULNERABILITY ANALYSIS OF UNDERGROUND AQUIFERS TO CONTAMINATION USING THE DRASTIC METHOD AND RISK DETERMINATION

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ABSTRACT

Groundwater represents an important component in the supply of freshwater in several regions around the world. The contamination of these waters is a worrisome problem in the management of water resources. Since underground aquifers are vulnerable to contamination by human and industrial activities, including land use, the diagnosis associated with land use is critical for environmental management. The present study was carried out in the Uberaba sandstone formation, in which the vulnerability of the subterranean aquifers was determined using the DRASTIC method, by evaluating the interaction between the use and occupation of the land using a geographic information system. Thus, the risk of contamination of the underground aquifer was determined by evaluating the land use with the water quality and fertility. The tool applied in the present study proved effective for the diagnosis, management and action planning in the short and long term, with the intention of preserving these natural resources.

Keywords: Land use and occupation. Risk of contamination. Groundwater. DRASTIC.

ANÁLISE DA VULNERABILIDADE DE AQUÍFEROS SUBTERRÂNEOS À CONTAMINAÇÃO ATRAVÉS DO MÉTODO DRASTIC E DETERMINAÇÃO DE RISCO

RESUMO

As águas subterrâneas representam um importante componente no suprimento de água doce em diversas regiões do mundo. Em função dessa relevância para a humanidade, a contaminação destas águas é um problema preocupante na gestão dos recursos hídricos. Sendo os aquíferos subterrâneos vulneráveis à contaminação pelas atividades humanas e industriais, incluindo o uso da terra, o seu diagnóstico associado à ocupação dos solos é fundamental para gestão ambiental. O presente estudo foi realizado na formação arenítica Uberaba, na qual se determinou a vulnerabilidade dos aquíferos subterrâneos, através do método DRASTIC, avaliando a interação com o uso e ocupação dos solos mediante uso de um sistema de informação geográfica. Desta forma, determinou-se o risco de contaminação do aquífero subterrâneo, associando o uso dos solos com a qualidade hídrica e a fertilidade. A ferramenta aplicada no presente estudo se mostrou efetiva tanto para o diagnóstico, bem como para a aplicação na gestão e planejamento de ações em curto e longo prazo, visando à preservação destes recursos naturais.

Palavras-chave: Uso e ocupação do solo. Risco de contaminação. Águas subterrâneas. DRASTIC.

INTRODUCTION

Groundwater sources are an important component in the supply of freshwater in several regions of the world, and their relevance to humans and to ecosystems makes contamination a troubling problem in water resource management.

Freshwater is under threat due to population growth, urbanization and industrial activities as a lot of the available water is contaminated by pollutants. Groundwater is vulnerable to contamination by human activities (SHRESTHA; KAFLE; PANDEY, 2017), and is linked to terrain and land use (LERNER and HARRIS, 2009). Contamination in rural areas is determined by several factors, including land use (VALLE JUNIOR et al., 2014).

The first step to generate useful information for the development of groundwater protection strategies is determining vulnerability and identifying areas most at risk (SHRESTHA, KAFLE; PANDEY, 2017). In this sense, vulnerability studies of aquifers and hydrographic basins have been developed, such as the conflict between the potential and the use of the land through Geographic Information Systems - GIS tools (VALLE JUNIOR et al., 2014; PACHECO and FERNANDES, 2016). In the region of the present study, environmental vulnerability studies have been done to determine the risk road spills of hazardous substance have on groundwater using multicriteria modeling, taking into account physical attributes that influence the quality of groundwater (SIQUEIRA et al., 2017; MACHADO et al., 2018a; MACHADO et al., 2018b).

Through GIS tools and aquifer vulnerability assessment, studies such as the modification of the DRASTIC model can be cited to understand the relationship between the risk of contamination and the slope of mountainous areas (PACHECO et al., 2018), risk of contamination assessment by quantifying hazards, modification of the DRASTIC model and groundwater value (WANG; HE; CHEN, 2012), and weighting factors in the DRASTIC model to assess the impact of this change on aquifer vulnerability indices (PACHECO et al. 2015).

Guiguer and Kohnke (2002) observe that there are several methodologies for determining the vulnerability of aquifers, with DRASTIC being the most used (ALLER et al., 1987). In this context, the present study aimed to determine the vulnerability of underground aquifers in the area of the Federal Institute of Triângulo Mineiro, Campus Uberaba Brazil, through the DRASTIC method and to determine its relationship with the actual risk of contamination from the use and occupation of the land.

In this context, the present study aimed to determine the vulnerability of underground aquifers in the area of the Federal Institute of Triângulo Mineiro, Campus Uberaba Brazil, through the DRASTIC method and to determine its relationship with the actual risk of contamination from the use and occupation of the land. Thus, it is intended to verify whether the geographic information system in conjunction with the DRASTIC method is efficient in diagnosing the vulnerability of the underground aquifer, as well as its potential risk, to favor the proper planning in the occupation of the area.

MATERIAL AND METHODS

Area of study

The Federal Institute of Education, Science and Technology of the Triângulo Mineiro Campus Uberaba (IFTM), is located in the Industrial District II in the city of Uberaba-MG in Brazil, between the average coordinates 19°39'49"S latitude and 47°58'09"O longitude, has a total area of approximately 4.68 Km^2.

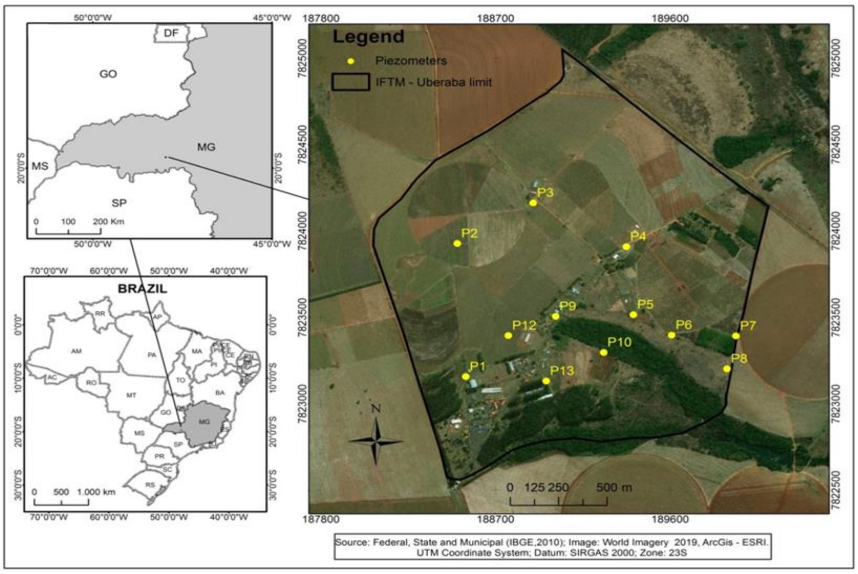
The climate of the region is qualified as Aw according to the Köeppen classification. The Aw climate is a tropical mega-thermal climate, with dry winters and an average temperature of over 18ºC in the coldest month. Annual precipitation averages from 1200 to 1450 mm, according to the map of average climate in Brazil 1961-1990 from the National Meteorology Institute (INMET, 2016). The rainy season is characterized between October and March and the dry season runs from April to September, where precipitation is more intense between the months of December and January (ABDALA, 2012). Geologically the region under study corresponds with the Brazilian Central Plateau, a sedimentary geotectonic called the Sedimentary Basin of Paraná. The area is located in the northern / northeastern portion of this basin presenting stratigraphic rocks of the São Bento Group (basalts of the Serra Geral Formation) superimposed by the sandstones and conglomerates of the Bauru Group (sandstones of the Uberaba Formation and Marília Formation), with much of the area covered with Cenozoic sediments (recent alluvial sediments) (VALLE JUNIOR, 2008).

Regarding the soils, Nishiyama (1989) mentions that the municipality of Uberaba has varied types of soil with mostly average texture, generally classified as Latosols with different degrees of fertility. These predominately include typical Dystroferric Red Latosol (LVdf), typical Dystrophic Red Latosol (LVdt) and typical Dystrophic Yellow Red Argisol (PVAd). In the evaluated area, the class Red Latosol and Red Nitosol are prevalent.

Groundwater collection

The IFTM Campus has 15 piezometers installed at different points, where 12 points were used to monitor the water table and water intake and 3 were discarded because they were inoperative (Figure 1). Piezometers were drilled with a 100 mm drill and subsequently installed PVC pipes with a diameter of 40 mm between 4 and 31 m deep. The drilling took place under the Uberaba formation, formed by sandstones, volcanic rocks, conglomerates and pelite, which has an average thickness of 75m in the region (LIMA; ALMEIDA, 2012). The samples were collected using a graduated PVC tube with a volume of 250 ml, then stored in plastic bottles and refrigerated until analysis was done. The collection was carried out over three periods: March, April and May 2018.

Figure 1 – Uberaba (MG): Location of piezometers on the IFTM campus.



Source: The Authors (2019).

The water samples were analyzed for the following parameters: calcium, potassium and nitrate, pH, electrical conductivity, and total and thermotolerant (fecal) coliforms. The values were subdivided into five classes: class 1 (minimum values), class 5 (maximum values) and class 2 to 4 (medium values). Calcium (Ca), Potassium (K) and Nitrate (NO^{-3}) quality parameters were analyzed using specific Horiba LaquaTwin® probes for each parameter.

The values of pH (actual number up to 2 decimal places) and electrical conductivity (microsiemens/cm (µS/cm)) of each sample were analyzed in the Laboratory of Soil and Foliar Tissue Analysis of the IFTM Uberaba Campus.

The water samples for coliform analysis were collected in sterile polyethylene bottles and analysis was started immediately. Fecal coliform analysis was performed at the IFTM Microbiology Laboratory, using 200ml of water from each sampling point. At each piezometer, three samples were selected. Analysis of Coliforms in water was done using the method American Public Health Association (APHA) for Most Probable Number (MPN). The interpolated water quality maps were generated with the water quality data and the 12 geo-referenced piezometers.

Collection of soil samples and mapping of fertility parameters

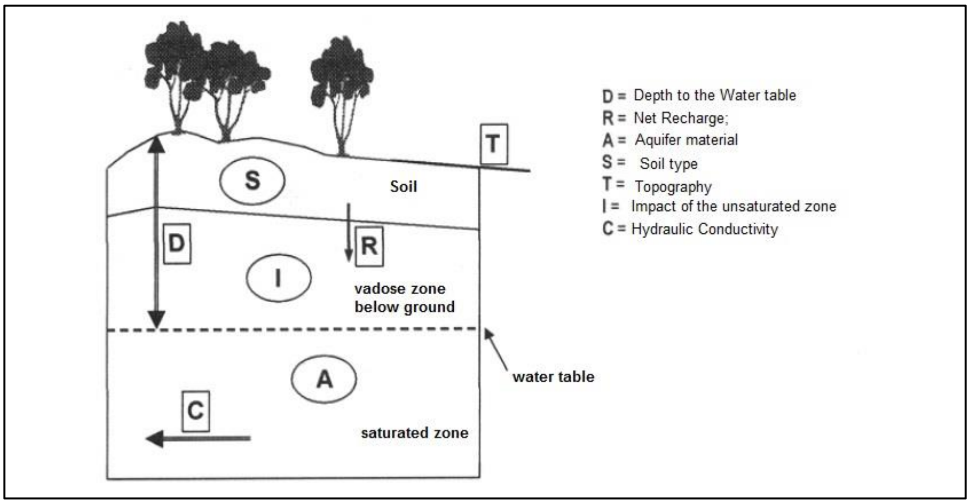
Disturbed samples were taken with the use of Dutch trawls at depths of 0 to 20cm in 50 geo-referenced points and distributed in quadrants spaced every 250m along the Uberaba campus, with 12 additional samples taken at random points. Soil samples were sent to the laboratory where the chemical content of the soil was analyzed, and the fertility classes were determined for each element as described by Raij (1996).

The granulometric analysis of the soil samples were performed according to the pipette method described by Teixeira et al. (2017). After identifying the respective fertility parameters evaluated, the georeferenced values were interpolated into a geographic information system (GIS). The inverse method of distance was then used on the 62 points under analysis in QGIS 2.18 to make the respective maps.

Diagnosis of Aquifer Vulnerability - DRASTIC Methodology

According to Aller et al. (1987), the DRASTIC method was developed by the US Environmental Protection Agency (EPA) and calculates an intrinsic vulnerability index based on a weighted addition of seven characteristics that form the acronym DRASTIC: D (Depth to the water table); R (Recharge); A (Aquifer material); S (Soil type); T (Topography); I (Impact of the vadose zone); C (Conductivity) (Figure 2).

Figure 2 - Parameters incorporated in the DRASTIC model



Source: adapted from Pacheco (2012)

The DRASTIC index (Lobo Ferreira and Oliveira, 1995) corresponds to the weighted sum of 7 values corresponding to the following parameters or hydrogeological indicators:

1) Depth to the Water table;

Table 1 – Parameter D - Depth of unsaturated zone

Depth (m)	**< 1.5**	**1.5-4.6**	**4.6-9.1**	**9.1-15.2**	**15.2-22.9**	**22.9-30.5**	**>30.5**
Rating Scale	10	9	7	5	3	2	1

Source: adapted from ALLER et al. (1987); Pacheco (2012).

2) Net Recharge;

Table 2 - Parameter R- aquifer recharge

Recharge (mm year^{-1})	**< 51**	**51-102**	**102-178**	**178-254**	**>254**
Rating Scale	1	3	6	8	9

Source: adapted from ALLER et al. (1987); Pacheco (2012)

3) Aquifer material;

Table 3 – Parameter A - Aquifer material, the type of rock, the existence of fractures interferes with hydraulic conductivity.

Aquifer nature	**Rating**	**Typical Rating**
Massive shale	1-3	2
Igneous/ metamorphic rock	2-5	3
Altered ígnea/metamorphic rock	3-5	4
Glacial Till	4-6	5

Aquifer nature	Rating	Typical Rating
Sandstone, limestone and claystone	5-9	6
Massive sandstone	4-9	6
Massive limestone	4-9	6
Sand and Gravel	4-9	8
Basalt	2-10	9
Karst limestone	9-10	10

Source: adapted from ALLER et al. (1987); Pacheco (2012)

4) Soil type;

Table 4 - Parameter S - Soil type

Soil	Typical Rating
Thin or absent	10
Gravel	10
Sand	9
Peat	8
Aggregated and or expandable clay	7
Sandy loam	6
Loam	5
Silty loam	4
Clay loam	3
Muck (sludge)	2
non-aggregated and non-expandable clay	1

Source: adapted from ALLER et al. (1987); Pacheco (2012)

5) Topography;

Table 5 - Parameter T - Topography

Slope (%)	<2	2-6	6-12	12-18	>18
Typical Rating	10	9	5	3	1

Source: adapted from ALLER et al. (1987); Pacheco (2012)

6) Impact of the unsaturated zone;

Table 6 – Parameter I - Impact of the unsaturated zone.

unsaturated zone	Rating	Typical Rating
confining layer	1	1
Silty/Clay	2-6	3
Shale	2-5	3

unsaturated zone	Rating	Typical Rating
limestone	2-7	6
sandstone	4-8	6
stratified sandstone, limestone and claystone	4-8	6
sand with a significant percentage of silt and clay	4-8	6
Metamorphic/Igneous	2-8	4
Sand and Gravel	6-9	8
Basalt	2-10	9
karst Limestone	8-10	10

Source: adapted from ALLER et al. (1987); Pacheco (2012)

7) Hydraulic Conductivity.

Table 7 – Parameter C - Hydraulic Conductivity

Hydraulic Conductivity (m d^{-1})	Typical Rating
<4.1	1
4.1 – 12.2	2
12.2 – 28.5	4
28.5 – 40.7	6
40.7– 81.5	8
>81.5	10

Source: adapted from ALLER et al. (1987); Pacheco (2012)

The 7 values are assigned numbers r from 1 to 10 depending on the range of values that represent the conditions of the area under analysis. These are multiplied by weights w ranging from 1 to 5, the most significant factor having a weight of 5 and the least significant 1. Therefore, the DRASTIC parameters for generic vulnerability situations have weights 5, 4, 3, 2, 1, 5 and 3, respectively.

$$\text{DRASTIC Index} = DrDw+RrRw+ArAw+SrSw+TrTw+IrIw+CrCw \quad (1)$$

For quantification of the DRASTIC index, the Quantum Gis Software 2.18 is used through the map calculator tool.

Risk Assessment

To estimate the actual risk, the nitrate concentration method was used, which was developed on the basis that the groundwater of a given region which presents a potential risk of being contaminated is determined by the following formula:

$$\text{Potential Risk} = \text{Intrinsic Vulnerability} + \text{Specific Vulnerability} \quad (2)$$

Intrinsic vulnerability is determined by the 7 parameters of the DRASTIC model, in its original version, and the specific vulnerability is determined by land use (L). Antonakos and Lambrakis (2007) presented the specific vulnerabilities associated with different land uses, according to the criteria. The actual risk is what can be measured at a specific time by comparing the potential risk with the concentrations of nitrates observed at the same time. In case nitrate concentrations exceed legal limits, the risk indices of these sites correspond to effective contamination indices.

To calculate the potential risk, where the values of DRASTIC in the original version are known, the following equation applies:

$$\text{Potential Risk} = \text{DRASTIC} + 4L \quad (3)$$

Table 8 – Values of parameter L, corresponding to land use and occupation.

Land use / occupation	Values of parameter L
Resinous forests	1
Hardwood forests	1
Mixed forest	1
Transition zones	2
Irrigated crops	3
Degraded forest spaces	4
Mineral exploration	4
Natural pasture	5
Rainfed cultivation	5
Pasture	5
Olive groves	6
Roads and railways	7
Orchards	8
Sport structure	8
Grapevines	9
Urban area	10

Source: adapted from Antonakos and Lambrakis (2007); Pacheco (2012)

Thus, the maximum and minimum potential values are 27 and 266, respectively, so a normalized map of this parameter can be determined by applying the formula:

$$\text{Normalized Potential Risk } = \frac{\text{Potential Risk -27}}{239} \quad (4)$$

Drafting of Maps for Water Quality, Soil Fertility, Land Use and Occupation, and DRASTIC

Using the QGIS 2.18 software, maps were generated for each of the DRASTIC parameters. Maps for the water parameters were generated with the use of GIS tools, and georeferenced values of the piezometers were interpolated through the inverse distance method. The map of land use and occupation was made possible by means of vector digitalization, using GIS in the Google Maps menu to access the Google image from the year 2018. Soil fertility maps were computed using the inverse distance method at the 62 points under analysis in QGIS 2.18.

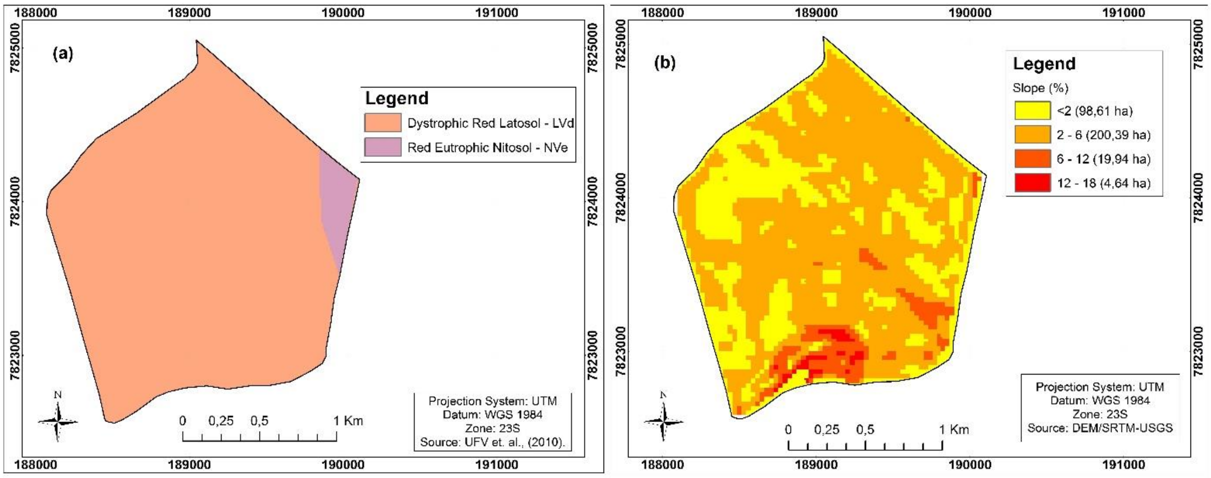
Through the SIG IDRISI Selva (EASTMAN, 2012) in the tool Crosstab, that performs a matrix of analysis and a comparison between the maps allowing for the observation of the interactions between the maps from the cross tabulation that compares images containing categorical variables.

RESULTS AND DISCUSSION

Physical and chemical soil factors

In the studied area, there is a predominance of the classes of Dystrophic Red Latosol and a small portion of Eutrophic Red Nitosol. In relation to the slope of the terrain, most of the land has a slope of between 2 and 6%, followed by areas with a slope less than 2%, and just a few areas have a slope of above 6%. Figure 3 shows the soil and slope classes in the studied area.

Figure 3 - Map of soil class (a) and terrain slope (b).



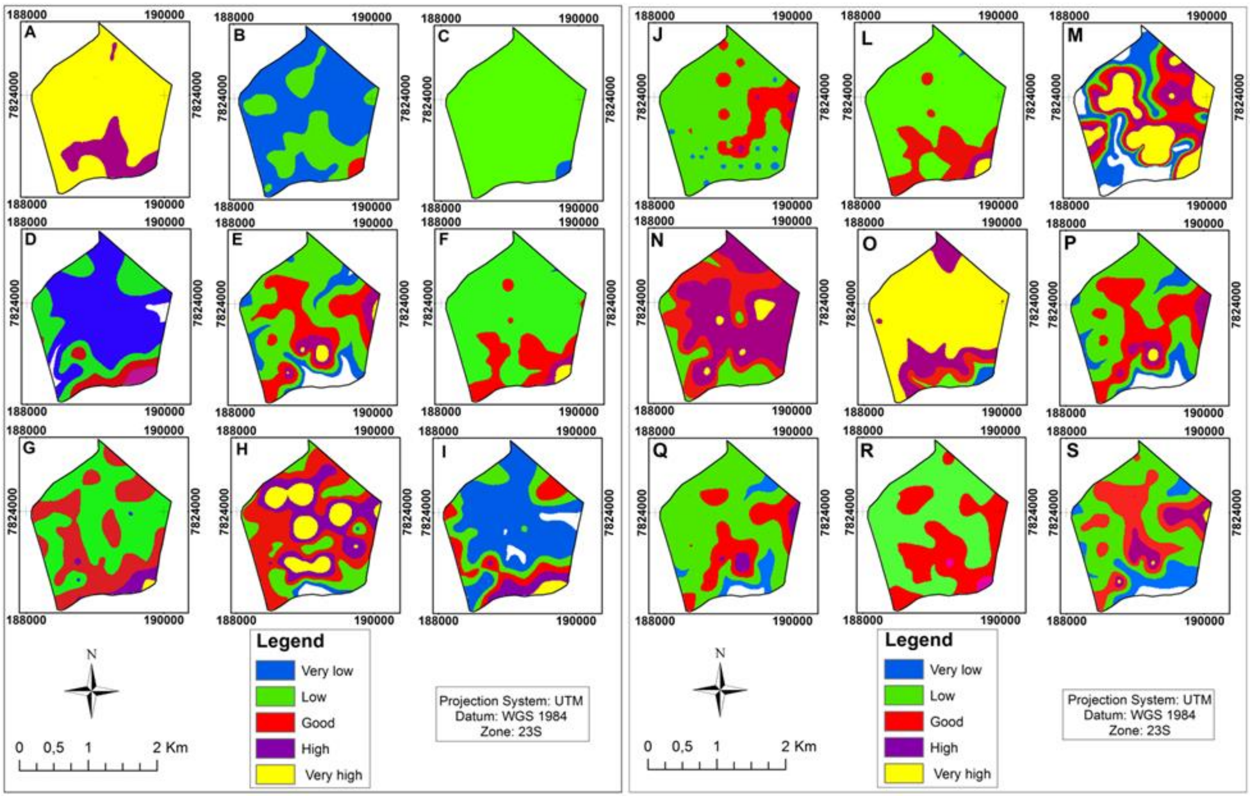
Source: The Authors (2019).

In relation to the physical and chemical attributes of the soil (Figure 4), sand (A) is generally observed to be the component in the greatest concentration. The attributes Al (D), Ca (E), C.org (F) and H+Al (G) were found in quantities considered very low to good. For Potassium, the concentrations vary from good to very high distributed throughout the studied area, which is probably due to the practice of fertilization with potassium. The attributes m% (I), Mg (J) and M.O (L) presented low levels which together with the low Al levels indicate that the soil is not acidic. The low concentration of Al found in the studied area can be explained due to the use of limestone, as the land use is predominantly for agricultural purposes.

As for P (M) content, since the soil is sandy, the Mehlich extractor finds significant values of phosphorus, pH (N) and residual P (O), ranging from levels considered good to very high and distributed throughout the area under study.

In the base sum - SB (P), effective CTC - t (Q), CTC at pH7 (R) and base saturation - V% (S) were mostly between the levels considered very low, low and good. This indicated that exchangeable cations were not available in high amounts, which also produced low values for effective CTC, CTC at pH7 and V%. This should be taken into account when making decision about fertility management and limestone application.

Figure 4 - Maps with atributes and parameters of soil fertility

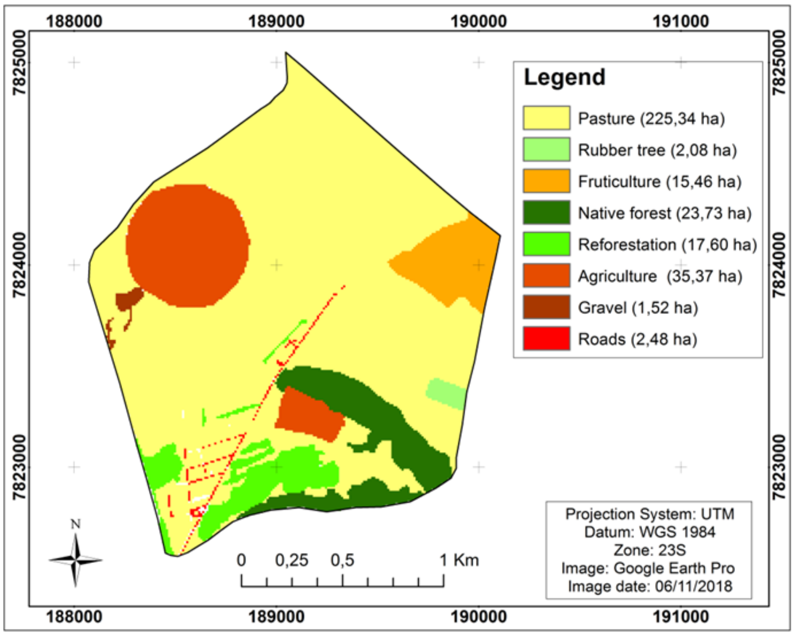


Subtitle:A (sand); B (silt); C (clay); D (Al); E (Ca); F (COrg.); G (H+Al); H (K); I (m), J (Mg); L (MOrg.); M (P); N (pH); O (residual P); P (SB); Q (t); R (TpH7); S (V). Source: Sargentim (2018).

Land use and occupation

The land is mostly used as pasture, followed by agricultural crop growing activity (including fruit farming), and after, native forest and reforestation. The other uses are less significant as can be seen in Figure 5.

Figure 5 - Map of land use and occupation in the studied area



Source: The Authors (2019).

Groundwater quality

As shown in Figure 6, the pH of the groundwater was between 5.44 and 6.33 in the region with the highest declivity, characterized by agriculture and native forest. Groundwater pH samples collected in the region of Uberaba-MG showed a pH below 6 (Ferreira et al., 2015). The decrease in pH values may be associated with an imbalance of chemical compounds present in water, the presence of organic matter or anthropic factors linked to contamination (VON SPERLING, 2005). The Mineiro Triangle is regarded as a region with vulnerability to groundwater contamination, given the intense agricultural activity and urban agglomerations (LIMA; ALMEIDA, 2012) The recommended pH range for human consumption is 6 to 9.5 according to Ordinance nº 2914 / 2011 from the Ministry of Health (BRASIL, 2011).

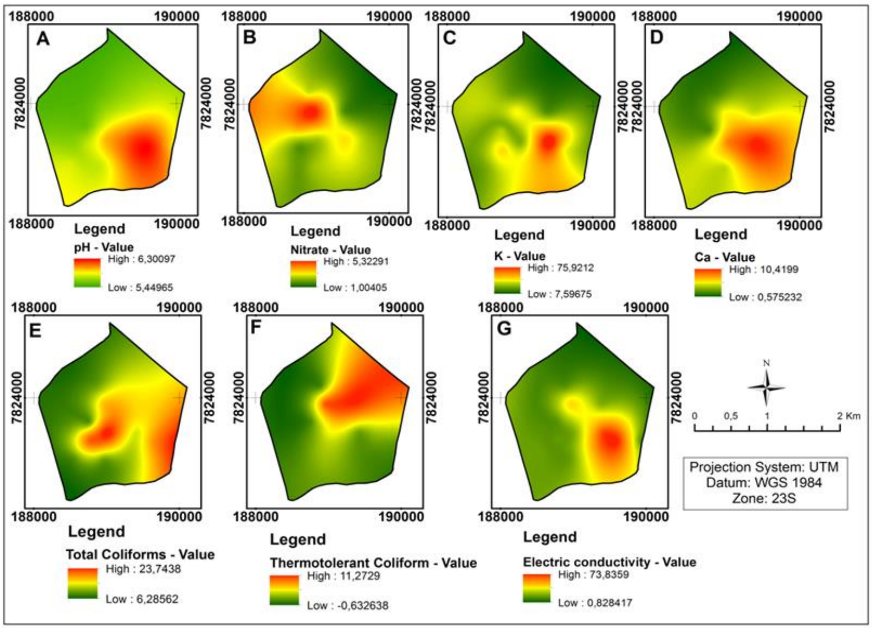
The highest average for Nitrate (NO^{-3}) was around 5.32 mg / L on the west portion of the campus, where agricultural activities and cattle farming are concentrated. However, the water potability standard in Brazil, defined by Ministerial Order nº 2914 / 2011 of the Ministry of Health (Brasil,2011), establishes the maximum permissible value of 10 mg/ L. In other words, the values found in the study area are within the values established for human consumption. Lerner and Harris (2009) observed that agricultural nitrate leaching into groundwater can be significantly reduced by good agricultural practices. However, even if nitrate leaching was stopped immediately it would take many decades, or even centuries, for most nitrate concentrations to decrease. Thus, although the parameters are within the established values, it is necessary to monitor nitrate levels in the area to avoid an increase caused by the use and occupation of the soil in the area.

Ca and K also had the highest averages: ≈75.92 and 10.41 mg / L respectively, in the eastern portion where the vegetable crops, native forest and a piggery are located. This can be explained by the fact that potassium and limestone-based fertilizers are used and, also, these nutrients are used in the animal feed. Thus, providing evidence that land use and occupation affect groundwater. This result is also common for the electrical conductivity parameter that found an average of 73.83 µS / cm in the area of the vegetable crops and piggery, which is in accordance with the presence of high concentrations of these ions in the groundwater because of the use of fertilizers and/or animal feed. However, Corwin and Lesch (2005) affirm that the relationship is very complex and still poorly understood, especially when dealing with a diversity of soils with variations in texture and levels of organic materials, since these attributes influence this parameter, directly or indirectly.

The total coliform analysis shows a range of values between 6.28 and 23.74 NMP, the highest values for this parameter also occupied the eastern portion of the campus where activities involving poultry and swine are predominant. This area also includes buildings with toilets. The highest averages for thermotolerant coliforms were concentrated in the region occupied by pastures and fruit farming.

It should be noted that the maps showing the results of groundwater quality consider the values according to the range of classes established by the software, and not necessarily related to parameters established by the legislation.

Figure 6 - Maps with groundwater quality parameters



Subtitle: A (pH); B (Nitrate); C (K); D (Ca); E (Total Coliform); F (Thermotolerant Coliform.); G (Electric conductivity)

Source: The Authors (2019).

DRASTIC model

D - Depth of the unsaturated zone, estimated using the piezometer records, ranged from 2.61 m to 15.23 m, identifying the hydrostatic level range classes (m): 15.2 - 22.9; 9.1 - 15.2; 4.6 – 9.1; 1.5 - 4.6 to generate the indices (3,5,7 and 9), respectively Figure 7-D.

R - The parameter Groundwater Recharge (R) which is the amount needed to recharge the estimated aquifer (mm / year) by land use was: Agricultural crops (154.1), Pasture (225.5), native forest(297.9 mm / year), identifying the recharge interval classes (mm.year-1): 102 - 178; 178 - 254; > 254 to generate the indices (6, 8 and 9), respectively Figure 7-R.

A - The parameter Material of the Aquifer (A). The geology predominant in the area is sandstone, (6) Figure 7-A.

S - The type of soil (S), the predominant soils in the area are of the sandy loam textural type, thus index (6) (Figure 7-S).

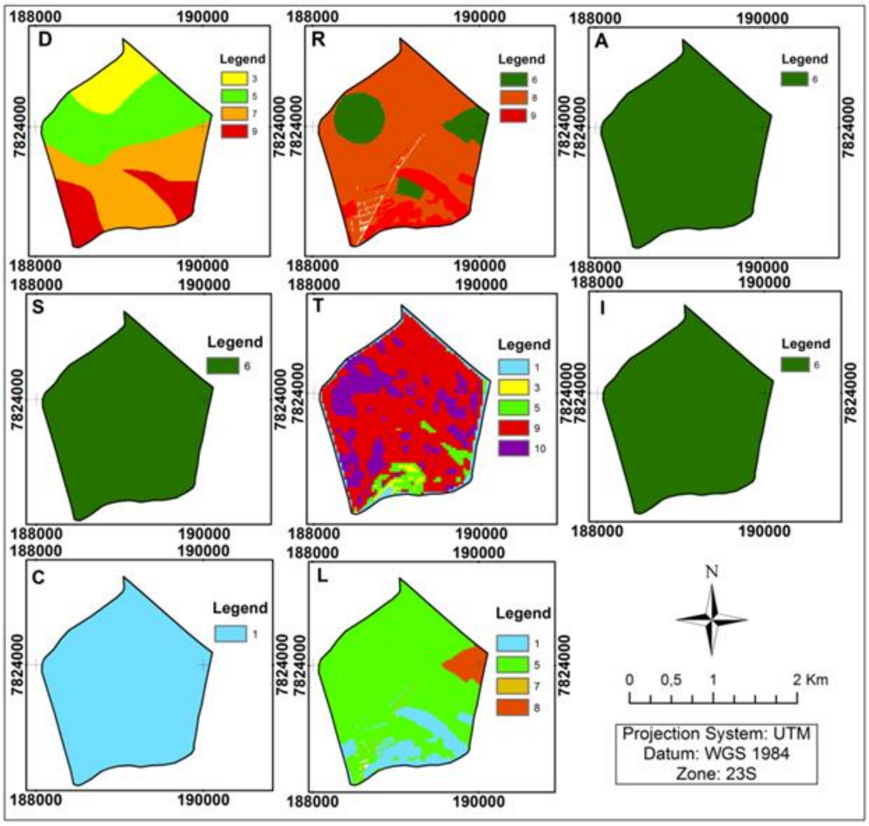
T - The Topography (T) parameter, when constructing the terrain map (Figure 2), identified the slope classes: < 2, 2 to 6, 6 to 12 and 12 to 18, with the indices being adopted (10,9,5 and 3) (Figure 7-T).

I - The parameter Impact of the Unsaturated Zone (I), being the unsaturated sandstone zone has index (6) (Figure 7-I).

C - The Hydraulic Conductivity parameter (C) adopted the hydraulic conductivity as high, reflecting the index (6) (Figure 7-C).

The land use factor generated indices (1, 5, 7 and 8) (Figure 7-L).

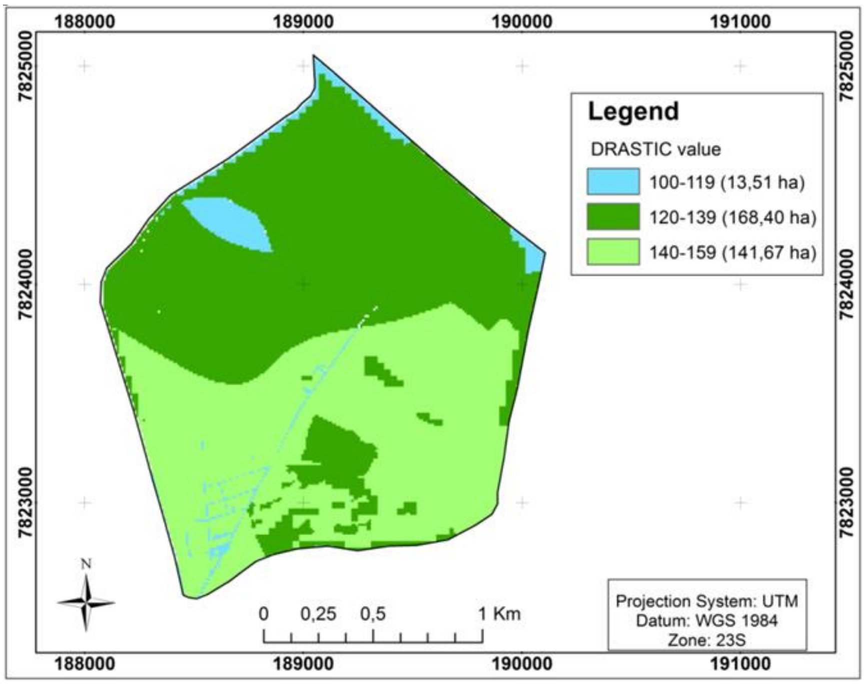
Figure 7 - Parameters used to build the DRASTIC vulnerability



Source: The Authors (2019).

After operation of maps made in the GIS, 3 levels of vulnerability for DRASTIC were found, being level 3 (100 - 119), level 4 (120 - 139) and level 5 (140 - 159) (Figure 8). According to Aller et al. (1987) the DRASTIC model presents 10 indexes of vulnerability where 1 is the least vulnerable and 10 the most vulnerable.

Figure 8 - DRASTIC aquifer vulnerability map



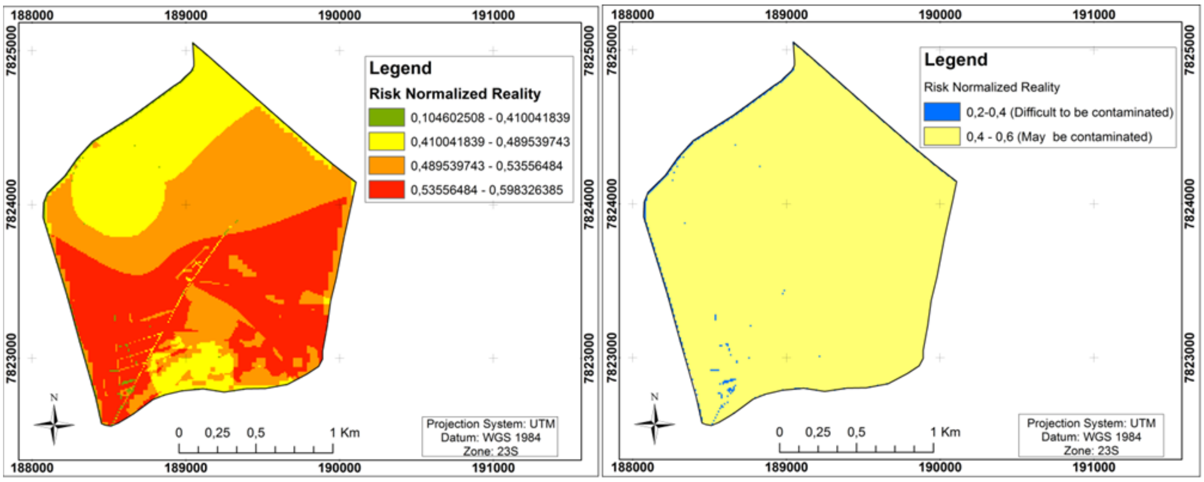
Source: The Authors (2019).

Paralta; Francés; Ribeiro (2005), observed that the DRASTIC method for determining the vulnerability associated with a GIS plays an important role since it allows: (1) integration, organization and structuring of geographic data, (2) interpolation of a database to generate different thematic maps of vulnerability and risk assessments, (3) overlaying a variety of maps, (4) assigning weights and rates to each hazard, and (5) calculating vulnerability and risk indices using tools available in the software.

Normalized potential risk

The normalized potential risk map presents 4 contamination risk bands distributed throughout the IFTM Campus Uberaba area, which after reclassification present us with 2 indexes: Level 2 (0.2 - 0.4) difficult to be contaminated and the level 3 (0.4 - 0.6) may be contaminated as shown in Figure 9.

Figure 9 - Normalized potential risk map and reclassified in the study area.



Source: The Authors (2019).

Crossing maps

Land use and occupation x DRASTIC

Three indexes of DRASTIC (3, 4 and 5) were observed in the IFTM area, with the majority of land use being concentrated within these 3 indexes, for example, 98.83% of the pasture areas and 99.57% of the fruit farming area, are present in the DRASTIC indexes > 2. 100% of the areas designated for the rubber plantation, native forest and agricultural crops, was at DRASTIC indexes > 2.

Use and occupation of land x Risk

Regarding the risk where risk classes 2 and 3 were obtained, 98.12% of the entire area of the IFTM Campus Uberaba is within risk class 3 in that it is possible to be contaminated.

Land use and occupation x Soil parameters

Analyzing each soil parameter in the areas with different uses within the study area, levels classified as 1 and 2 were very low and low, respectively. These are below the level considered to be good, and level > 2 where values ranging from good to very high.

For Al (Al) levels 1 and 2 were found in 94.53% of the pasture area, which is also seen in 100% of the rubber plantation, agricultural crops and gravel area, and in 69.16% of the reforestation area. However, 68.62% of the native forest area is where the level of Al is > 2, a fact attributed to the intrinsic characteristics of the soil in the Cerrado, and in these places acidity correction does not occur.

In the soils of the IFTM Uberaba Campus, there is predominance of sandy soil and 100% of the areas have a sand content > 2. For clay content, 100% of the areas had levels of 1 and 2, and for silt, more than 70% of the areas occupied with pasture, agricultural crops, forest, among others also had very low levels of silt.

Calcium content (Ca) is very low and low (level 1 and 2) in 70.76% of the areas reserved for pastures and 87.3% of the rubber plantation. However, the calcium content is > 2 in 100% of the area reserved for fruit farming and 64.16% of the area with agricultural crops.

Organic carbon is present in very low and low levels in 82%, 97.06% and 90.66% of pasture, fruit farming and agricultural crop areas, respectively, but has a good to very high content in 71.43% of the rubber plantation and 88.35% of the native forest. Resembling organic C, the H + Al parameter occupies a level of > 2 in 68.25% of the rubber plantation, 77.4% of the native forest, followed by 85.44% of the reforestation area and has a level 1 and 2 in 100% of the area reserved for fruit farming, 57.63% of the pasture and 53.48% of the agricultural crop area.

K was found at levels of 1 and 2 in 62.3% of native forest More than 80% of the areas reserved for pasture, rubber plantation, fruit farming and agricultural crops are in the range where the K level varies from good to very high.

For the parameter "m", 83.39% of the pasture area, as well as 100% of the rubber plantation, fruit farming and agricultural crops and 93.02% of the gravel area are in levels 1 and 2. 84.99% and 70.45% of the native forest and reforestation areas, respectively, had "m" levels > 2.

Mg levels were > 2 in 97.88% of the fruit farming area. While M.Os were mostly found at levels of 1 and 2 in most areas, meaning that the organic material content is lower than what is considered good in 80.82% of the pasture area, 100% of the fruit farming area and gravel areas, and 86.81% of the area reserved for agricultural crops. 74.6% of the rubber plantation and 89.19% of the native forest had levels of M.O > 2.

Soil pH was > 2 in more than 80% of the areas reserved for the rubber plantation, fruit farming, pastures and agricultural crops.

For residual P, levels ranging from good to very high were obtained in 100% of the rubber plantation, fruit farming area, gravel area and agricultural crops, and in 98.55% of the pasture area. The same is true for P content that reached levels > 2 in 61.19% of the pasture area, 100% of the fruit farming area and 87.72% of the agricultural crop area. Only in 75.8% of the reforestation area and 88.57% of the gravel area were P levels found between very low and low.

In Sum of Bases (SB), levels 1 and 2 were evident in 67.83% of the pasture area, 92.31% of the rubber plantation and 74.94% of the reforestation area. This was different from area reserved for fruit farming and agricultural crops that showed levels > 2 of SB in 100% and 69.13%, respectively.

In 68.57% of the pasture area T pH 7 was at levels 1 and 2, the same occurred in 60% of the rubber plantation and 66.17% of the reforestation area. pH 7 is > 2 in 87.84% of the fruit farming area and 52.72% of the agricultural crop area. The "t" content is similarly > 2 in 97.07% of the fruit farming area. However, it is below levels considered good in 79.11% of the pastured area, 100% of the rubber plantation and gravel area, 60.84%, 79.72% and 78.06% of the areas occupied by native forest, reforestation and agricultural crops, respectively.

The V% content was at levels 1 and 2 in 65.66% of the pastured area, 100% of the rubber plantation, 62.52% of the native forest and 85.85% of the reforested area. While 99.79% of the fruit orchard and 61.55% of agricultural crop areas were found to have levels > 2.

These results are consistent with the values reported in research carried out at the IFTM, related to the occupation of cover plants (Mazetto Junior et al., 2019), when planting lettuce in a horticultural area (Ribeiro et al., 2019), in soybean irrigated area (Santos Neto et al., 2019; Da Silva et al., 2020), in the cultivation of rubber tree (Torres et al., 2020).

Land use and occupation x Water quality parameters

Correlating the parameters of groundwater quality with the use and occupation of the soil in the study area, the following results were found and divided into 3 levels: 1 (minimum), 2 - 4 (medium) and 5 (maximum).

Calcium (Ca) has a content level of 2 - 4 in 72.81% of the pastured area, in 84.13% of the rubber plantation, in 99.58% of the fruit farming area and in 98.89% of the reforested area. However, it obtained minimum values for the Ca content in 69.63% of the agricultural crop areas.

The electrical Conductivity of groundwater (Ce) obtained minimum values in 68.13% of the fruit farming area and 60.13% of the agricultural crop area, while medium values of Ce were found in 56.45% of the pasture area, 98.36% of the rubber plantation, 95.65% of the gravel area and 95.95% of the reforestation area.

Maximum values (level 5) of thermotolerant Coliforms were found in 71.37% of the fruit orchard. In other areas, such as in 95.24% of the rubber plantation and in 81.58% of the agricultural crop areas, the values obtained for thermotolerant coliforms fall within level 1. While total Coliforms reached level 5 in 100% of the rubber plantation, it was found at levels 2 - 4 in most of the other areas: in 86.26% of pasture lands, in 91.18% of fruit farming area and in 99.54% of agricultural crop area.

Potassium (K) prevailed at level 2 - 4, with medium values in 74.4% of the pasture land, 100% of the rubber plantation and agricultural crop area, 97.98% of the reforestation area and 65.9% of the fruit farming area.

Nitrate (NO^{-3}) also presented medium values in most of the areas, with 91.95% of the pasture lands, 100% of the rubber plantation and native forest, 88.49% of the fruit farming area and 86.71% of the agricultural crop area.

In relation to the water pH, maximum values were found in 56.26% of the rubber plantation and 80.65% of the native forest Medium values were found in 85.36% of the pasture lands, 99.37% of the fruit orchard, 98.71% of the reforested area and 91.58% of the agricultural crop area.

DRASTIC X Soil Parameters and Water Parameters

As a result of the presence of three DRASTIC indexes, it is possible to observe on the map (Figure 7) that there is a predominance of vulnerability index 4 (reduced to moderate vulnerability) and vulnerability index 5 (moderate vulnerability) in most of the total area.

When crossing of the DRASTIC maps with the soil parameters, 48.89% of the total area of the IFTM campus is at index 4 according to DRASTIC. Al content is very low and low (level 1 and 2). The sand content is > 2 (good to very high) in 84.11% of the area where vulnerability index 5 predominates. This high sand content in the soil composition of the campus is confirmed when we see that the levels of silt (95.94%) and clay (92.99%) are very low and low both in areas where vulnerability index according to DRASTIC is 4 and 5.

Calcium (Ca) has a content level of 1 and 2 in 33.12% of the where there is a DRASTIC index 4 and 23.34% where there is index 5.

48.02% of the total area is at DRASTIC index 4, where the organic carbon content is low. The same level of organic C is found in 24.52% of the area where the vulnerability is considered moderate (index 5).

Vulnerability index 4 was found in 31.15% of the area where H + Al is very low and low, while DRASTIC index 5 is present in 25.1% of the area where H + Al is > 2 (good to very high).

The Potassium content is > 2 in 44.33% and 32.79% of the total campus area with vulnerability indexes of 4 and 5, respectively.

Levels 1 and 2 of the "m" in 42.92% of the area was found where the vulnerability index is 4 and 28.14% where it is 5 according to Drastic.

Magnesium and organic matter are also in very low and low concentrations in 40.72% and 47.47%, of the areas where the vulnerability index is 4, and in 35.91% (Mg) and 23.9% (MO) of the areas where vulnerability is 5.

The pH of the soil was found at levels > 2 in 48.13% of the area with a vulnerability index of 4 and 34.71% of the area with a vulnerability index of 5.

Residual P is found at levels considered good to very high in 51.1% of the campus where the vulnerability is 4 and in 40.74% of the campus that has a vulnerability of 5 according to DRASTIC. Similarly, we have Phosphorus (P) with levels > 2 in 31.61% of the area with a DRASTIC index of 4 and 36.41% of the area with an index of 5.

For Sum of Bases the content is level 1 and 2 in 33.34% of the studied area where the DRASTIC index is 4 and 23.01% of the area where it is 5.

T pH 7 obtained a range of 1 and 2 in 37.02% of the studied area with a vulnerability index of 4, and where the vulnerability index is 5 (23.58%) the T 7 pH levels were > 2. However, for "t", most of area are where the content of this parameter was at levels 1 and 2 – 39.96% of the area with a vulnerability index of 4 and 29.26% with an index of 5.

V% also obtained very low and low levels in 29.53% of the area with DRASTIC index of 4 and in 26.91% of the area with an index of 5.

In 34.38% of the area where the vulnerability index is 4, medium values were obtained for Calcium in groundwater, the same content was found in 33.74% of the area where the DRASTIC index is 5.

Level 1 (minimum values) for electrical conductivity were obtained in 29.86% of the area with a DRASTIC index of 4. However, in 34.92% of the area where the vulnerability is 5 the values of Ce were at levels 2 - 4.

Minimum values of thermotolerant coliforms were found in 19.33% of the area, in 18% the values are medium and in 14% of the area the values reached level 5 where the vulnerability index was 4. Where the vulnerability index is 5 the values for thermotolerant Coliforms were considered minimum in 26.39% of the total area.

In the case of total coliforms, the values obtained were at level 2 - 4 in 50.86% of the area with a vulnerability index of 4 and in 32.6% of the area where the vulnerability index is 5.

The values of K in groundwater were also considered medium in 35.49% of the area with a DRASTIC index of 4 and in 40.83% of the area where vulnerability index is 5.

45.87% of the Campus area is considered moderate in terms of vulnerability with an index of 4 and 42.78% of the area has a DRASTIC index of 5. In both areas the Nitrate content obtained medium values (level 2 - 4). The same is seen for the pH of the water where medium values predominated in 78.59% of the total area, of which 50.54% is where the vulnerability index is 4.

Risk X Soil Parameters and Water Parameters

The study area presented two classes of risk of contamination: Class 2 (difficult to be contaminated) and Class 3 (possible to be contaminated); however, most of the area of the Uberaba Campus is included in Risk Class 3 with 98.12% of the area.

When correlating the risk of contamination with soil parameters, it is possible to observe very low and low values (levels 1 and 2) for Al in 86.95% of the area, Clay (99.27%), Ca (47.73%), Organic C. (76.14%), H + Al (53.68%), m (74.93%), Mg (79.99%), SB (57.71%), Silt (65.07%), T pH 7 (59.25%), t (71.59%) and V% (57.7%).

A level > 2 (good to very high) was obtained only in 99.28% of the area for sand, Ca (47.57%), H + Al (45.59%), 79.67% for K, pH (86.1%), remaining P (95.13%) and 70% of area for P.

In relation to water parameters classified as level 1, 2 - 4 and 5 within the areas where the risk class is also 3 (can be contaminated), medium values for almost all parameters prevailed. Levels 2 - 4 occurred in 69.13% of the area (Ca), 57.43% (Ce), 87.2% (total Coliforms), 79.04% of area for K, NO-3 (92.28 %) and pH (82.47%). Only for the thermotolerant coliforms, level 1 (minimum values) occurred in 48.16% of the area, followed by 34.68% with medium values and 15.96% of area with maximum values of this parameter.

CONCLUSION

The geographic information system in conjunction with the DRASTIC method is efficient to diagnosis the vulnerability of the underground aquifer as well as its potential risk (normalized risk). Soil occupation and use has a certain influence on the quality of the groundwater in sandy areas.

In the areas with pasturelands, contamination of the underground aquifer can occur, and thus, verifying the need for the adoption of suitable techniques for the application of agricultural products such as fertilizers and correctives, as well as emphasizing the importance of soil conservation. This demonstrates that the tools used in the present study, in addition to diagnosing the situation of the area, permit the planning of future actions, so as to manage the risk of contamination of underground aquifers.

ACKNOWLEDGMENT

The authors would like to thank the Coordination for the Improvement of Higher Education Personnel (CAPES) for supporting the master's program of the Federal Institute of Triângulo Mineiro (IFTM); The author, affiliated to the IFTM Renato Farias do Valle Junior, wishes to acknowledge the funding through a research grant from the National Council for Scientific and Technological Development (CNPq) - Proc. 307921 / 2018-2.

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Recebido em: 30/08/2020
Aceito para publicação em: 29/12/2020