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# Zoning of the use and quality of groundwater as a subsidy for the management of water resources: The case of the urban area of the municipality of Lençóis, Bahia, Northeastern Brazil

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## Abstract

The objective of this study is to zone the tubular well density and groundwater quality in the urban area of the city of Lençóis, Bahia, through geoprocessing techniques in the GIS platform. Lençóis, is a city of Chapada Diamantina, in the Brazilian Northeast that has in its territory tourism as main socioeconomic activities, receiving annually a high amount of visitors. The methodology used is based on data tabulation, kernel estimator runs for densities, and the Inverse Distance Weighted (IDW) algorithm for interpolation of nitrate and chloride contents. Both processes were executed in the ArcGis 10 software. The results showed the presence of a large zone with high density of wells in the central-east sector of the urban area of Lençóis, which presents high flow dynamics (vehicles, people), above to greater concentration of facilities such as hotels, inns, shops and restaurants. Notably, this sector has the greatest demand for water and needs to be monitored by competent institutions that seek to maintain a balance in the use of water resources, above to supply, even in periods of water stress. Inside this zone also traces of anthropic contamination occur, indicated by higher values of nitrate and chloride concentrations. This suggests that above to the pressure exerted by the high demand for water, there is inefficient management of wastewater and rainwater in this area of the urban area, compromising the quality of groundwater.

Keywords: Geoprocessing, spatial analysis, water resources, Chapada Diamantina

## 1. Introduction

In the current scenario of environment sciences, the search for instruments that can optimize costs and time in problem solving is increasing. Among these instruments, geotechnologies appear as potentially useful and widely applicable, and are increasingly present in various sectors of society. To this end, there is a growing need to master the tools of geotechnology, as well as spatial analyzes that are essential to obtain solid and practical results that solve the problems that arise in space and territory (Mattos et al., 2015; Silva et al., 2016).

Of course, the results of the spatial analyzes give an important aid to guide the management, be it of environment, energy, infrastructure, water resources, public health, among others. In the perspective of a proposal that interrelates supply issues with other socio-environmental and demographic aspects, it is known that one of the most effective ways to know the priority areas for water management is through the use of tools such as the Information

System Geographical (GIS). In the context of geotechnologies, this system, through geoprocessing and remote sensing techniques, is able to generate maps with concrete use demands for management (Thomalla et al., 2006).

In recent years, water resources questions on a global scale has been much debated, and in Brazil, this issue has particularly drawn attention to government, the media and the population itself that depends so much on water as a vital resource. The increasing demand for current supply, climate change, river basin degradation, and energy crises have caused socio-economic conflicts. Due to this scenario, the management of water resources has sought alternatives that minimize the current problems, and certainly, the use of geotechnologies has served as a basis for spatializing the profile and occurrences of surface and subsurface water (APHA, 2012). This work presents methodologies that generate products capable of assisting the territorial planning through the evaluation of the use of water resources, above to the pressures exerted on them. The main objective of this work is to zone through geoprocessing techniques the density of wells and groundwater quality in the urban area of the municipality of Lençóis, Bahia.

## 2. Material and Methods

### 2.1. Study of area

The analyzed area is located in the central portion of the state of Bahia, in the municipality of Lençóis between the geodesic coordinates 12º33’12”; 12º34’27” S e 41º23’49”; 41º22’43” W (Figure 1). Being its municipal headquarters, which has an area of just over 2 square kilometers. In the urban area of the municipality of Lençóis, an important socioeconomic activity is established that is the tourism, receiving about 120,000 tourists annually according to data of the secretary of tourism of Lençóis. Tourism generates many socio-economic resources; however, it must be properly managed, as the urban area's carrying capacity must be respected. In this scenario, the supply and demand of water should be given special attention by the public and private sector, since in times of drought the city suffers losses due to the lack of water in a significant volume in the rivers.

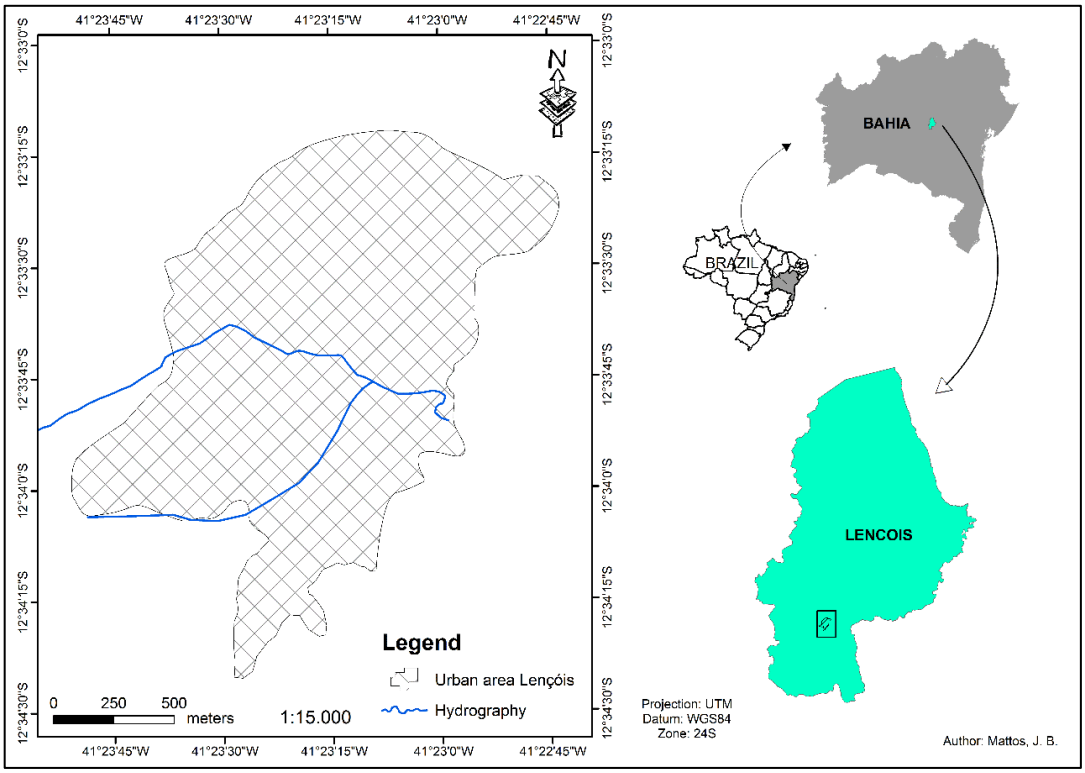


Figure 1 – Location of study area.

2.1.1 Climate

The climate in the urban area is of the Cwb type (tropical altitude) in the Koppen (1948) classification and presents two well-defined seasons with average annual rainfall ranging from 830 mm to 1192 mm (Silva et al., 2016). The local climatic characteristic has reflexes in the types of vegetation, being this a transition area between caatinga and cerrado (Brazilian savannah), besides containing some typical species of Atlantic Forest.

2.1.2 Geology and Hydrogeology

The rocks in the urban area are predominantly metarenites, conglomerates and quartzites that form part of the Chapada Diamantina Group (Tombador and Caboclo Formation), originated in the Mesoproterozoic Era (1.6 Ga), which has a quartzite and sandy stratigraphic domain of great thickness and relative variability, with Presence of stratigraphic intervals of psamitic sedimentation (Turra, 2014). According to CPRM (2005), groundwater in the Lençóis urban area is resident in the hydrogeological domain of metasediments (Tombador and Caboclo Formation), which is a fissural, semi-confined aquifer with secondary porosity represented by fractures.

2.2 Data tabulation

Data were tabulated and information was collected for the formulation of the metadata to be used in the processing (Table 1). There was a field campaign for collecting geodesic information from the tubular wells (x, y coordinates) in the WGS84 datum of the 24S Zone for planned projection (UTM) on a scale of 1: 12,500. The plasma laboratory of the Institute of Geosciences of the Federal University of Bahia (UFBA) provided the necessary data (hydrogeochemistry) to compose the z-column in the shapefile (shp) of the tubular wells of the urban area of Lençóis-BA and thus perform the processing in the Geographic Information System.

Table 1 - Description of the data used for processing.

| Data | Scale | References system | Year | Source |
|---|---|---|---|---|
| Shp. Bahia state | 1:5.000.000 | WGS84 (GCS) | 2007 | IBAMA (2007) |
| Shp. of Lençóis | 1:250.000 | WGS84 (GCS) | 2012 | CPRM (2012) |
| Shp. of urban área | 1:15.000 | WGS84 (UTM) | 2015 | Research data |
| Shp. of hydrography | 1:25.000 | WGS84 (UTM) | 2013 | Research data |
| Shp. of wells / with values of z-column | - | WGS84 (UTM) | 2016 | Research data |

2.3 Sampling (Hydrogeochemistry)

Fifteen points were defined for collecting samples of groundwater through tubular wells (Figure 2), which have an average depth of 81 meters. The criterion used to define the points was the availability of the wells. The collection was done according to the practical manual of water analysis (FUNASA, 2006) and with the methods internationally standardized by the Standard Methods for the Examination of Water and Wastewater (APHA, 2012).

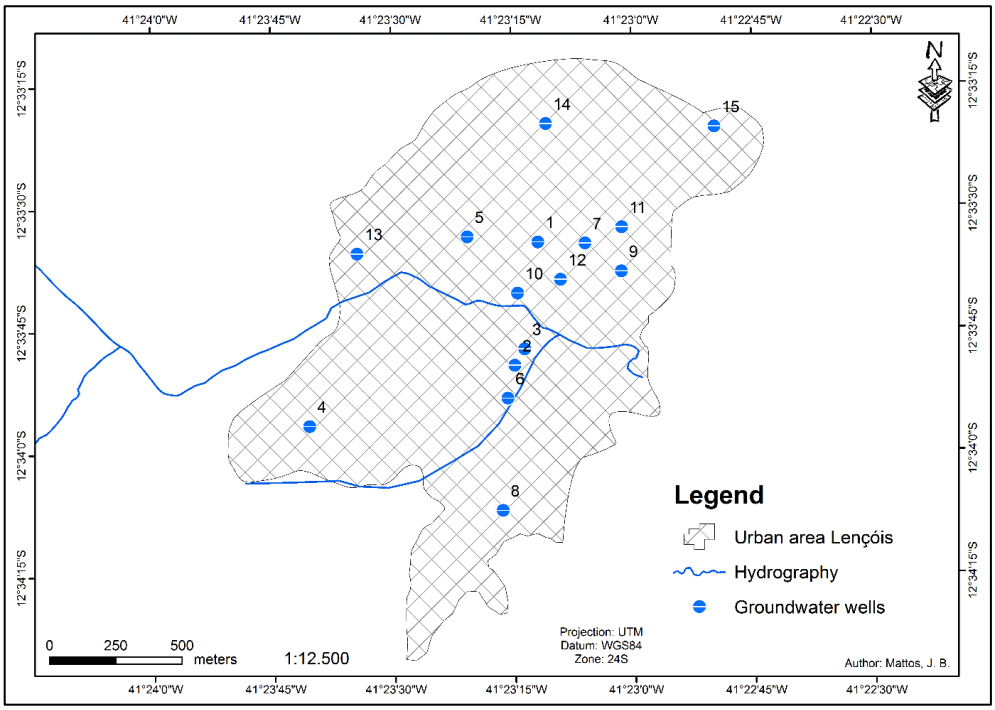


Figure 2 – Location of sample stations.

The Plasma Laboratory of the Institute of Geosciences of UFBA analyzed the collected samples. The parameters used as the basis for this work were the anions chloride and nitrate. To determine these anions, the samples were filtered at the sampling point itself using a 0.45-µm Milipore membrane vacuum pump. The chloride anion was quantified using the Mohr volumetric method, where the chloride ions were titrated with a standard solution of silver nitrate (AgNO3) 0.01 N in the presence of potassium chromate (K2CrO4) as an indicator (APHA, 2012). Nitrate was measured by the method of molecular absorption of monochromatic radiation in one of the regions of the electromagnetic spectrum by optical spectrophotometry through the spectrophotometer (HITACHI, model U-5100).

2.4 Spatial analysis

The spatial analysis methods chosen were the kernel estimator for zoning the groundwater well density and the Inverse Distance Weighted (IDW) interpolator. The results were based on ArcGis® version 10 software (ESRI, 2010) for the generation of density maps and isovalues of nitrate and chloride concentrations.

2.4.1 Kernel Estimator (density maps)

The Kernel estimator is a non-parametric statistical function that estimates the probability density of a random variable. With regard to geotechnology, this method estimates the density curves that are weighted by distance from a central value. In practice, in a map this estimator does not take into account the mean and the standard deviation, but rather the position of the checkpoints or sampling stations. According to Loyo and Barbosa (2015) the application of this estimator allows the aggregation of the information, generating on the thematic map a cluster that highlights hot spots (hotspots) in the analyzed area. Several recent studies in several areas of knowledge have presented satisfactory results with the use of the kernel estimator in the GIS to generate these density maps, as examples of Yu and Ai (2014) when using the kernel for urban facilities in the civil engineering area; Lopez-Aparicio et al. (2017) for the environmental area; Nasser et al. (2015), Santos et al. (2016), Sousa and Pinto Júnior (2016) and Dai and Jaworsky (2016) in generating density maps for studies related to epidemics, health and transport-transit, respectively. Other sectors such as public security, supply, education, have also been the subject of spatial analysis by the kernel estimator around the world.

2.4.2 Interpolation (IDW)

The IDW algorithm is a mathematical method that estimates a value for a non-sampled location as a mean of the neighborhood data values. According to Jimenez and Domecq (2008), the IDW interpolator weights weights at each of the closest points, representing a function of the inverse of a distance power. The success of this method in a given area of study will depend on the spatial distribution (position) of the points to be analyzed and is recommended for areas with high sample density. Based on the studies of Bartier and Keller (1996), Palaseanu and Pearlstine (2008), Gardiman Junior et al. (2012) and Mattos et al. (2015), the IDW method is punctuated among others as an efficient method, but depends on the compatibility of the data with its mathematical operations. In the form of thematic maps with continuous surfaces, IDW processing in GIS provides spatial information of multiple applicability, as can be observed in studies conducted by Carrera-Hernandez and Gaskin (2007), Dao et al. (2010), Mattos et al. (2015) and Zhang et al. (2016) when using IDW geostatistics to spatially represent precipitation, temperature, urban soil geochemistry, groundwater hydro-geochemistry and topography of river channels.

## 3. Results and discussion

The results are based on two pillars of analysis: density zones and water resources management vs. Geostatistics of maps, where each of the processes executed in the geographic information system is represented in maps with the intention of serving as an instrument for urban, environmental and water resources management.

3.1 Density zones

The map of Figure 3 shows that the Center-East zone of the urban area of Lençóis is the one that has greater access to groundwater, through a significant density of tubular wells. This density map illustrates to the municipal management institutions the sector of the urban area that needs to be monitored with greater attention, serving to raise awareness of well owners and holders of the use of groundwater for the care that must be taken to maintain the quantity and the quality of the water produced in the local a quifer at levels suitable for use.

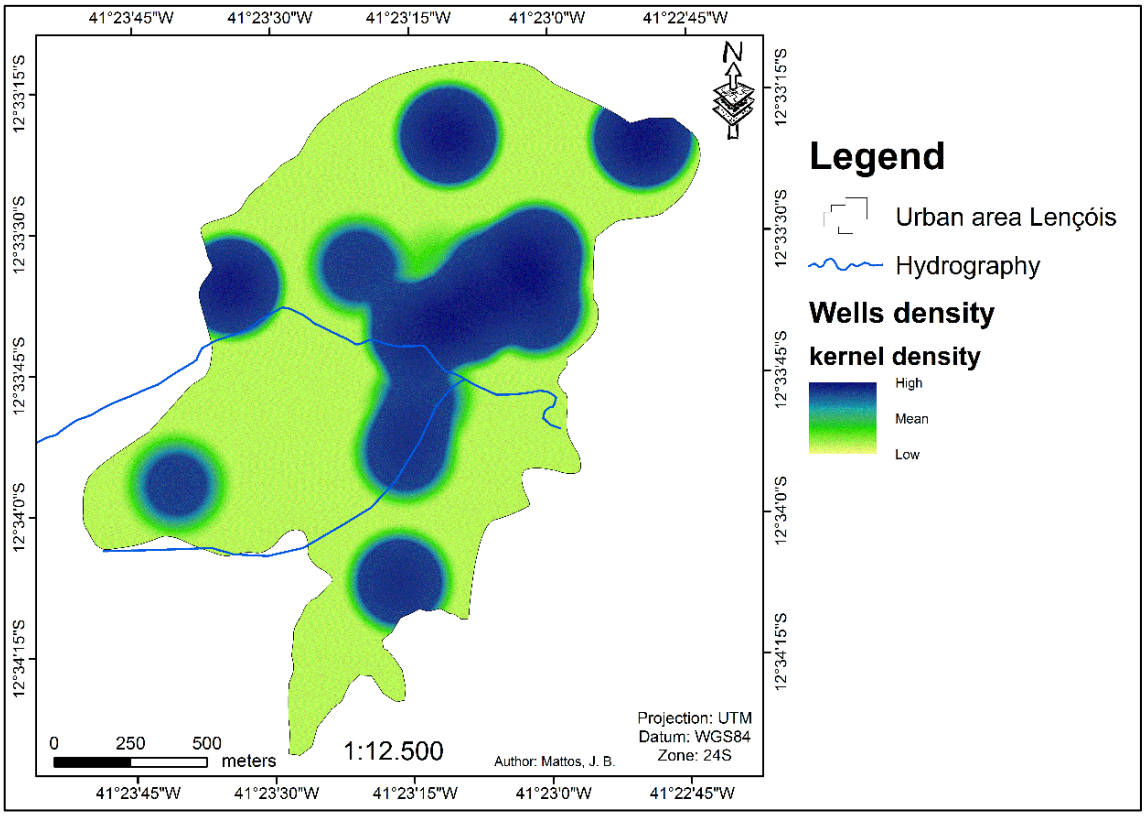


Figure 3 - Map with density zones of the groundwater extraction wells in the urban area of Lençóis-BA.

It is known that this zone contains a high number of hotels, inns, restaurants and above all a high flow of people (tourist agents-natives, guest-tourists) and vehicles, evidencing that there is a greater vulnerability of contamination of these waters when Compared to other areas of the city.

At this juncture, the density of the Kernel algorithm provided a cartographic product that allows the control of the activities developed in the denser zone, and it is possible to list a series of mitigation and prevention measures. These measures, if executed, can help in the process of groundwater protection, safeguarding the quality of this resource so strategic for the maintenance of the socioeconomic and environmental dynamics in the city of Lençóis. Other important measures that can take from the interpretation of the density map are the control and control of the use of groundwater in the zone of greater density, since the demand for water in this zone is high. These waters are also part of the same hydrogeological unit, and depending on the use may trigger an imbalance in the water availability of the subsurface saturated zones. The purpose of these measures would be to safeguard an adequate volume of water available, through controlled extraction and rational use, preventing underground sources from drying out in periods of water stress. From this base map (see Figure 3), it is possible to formulate other maps with zoning and weights assigned to each sector, and it is possible to assess the vulnerability, contamination risks, nature of the wells (public or private), among others.

### 3.2. Management of water resources x Geostatistics of maps

The Figure 4 illustrates a map that spatializes the concentration of the nitrate anion in the groundwater of the urban area of Lençóis, in it, it is possible to perceive that in the central sector where the highest density of wells in the city occurs the waters with the highest content of dissolved nitrate. The high concentrations of nitrate reflect the anthropic influence on water, since its presence in exploited waters in urban areas is associated with wastewater contamination that indicates poor management of solid waste and urban storm water, problems with domestic sewage leaks, above to septic tanks.

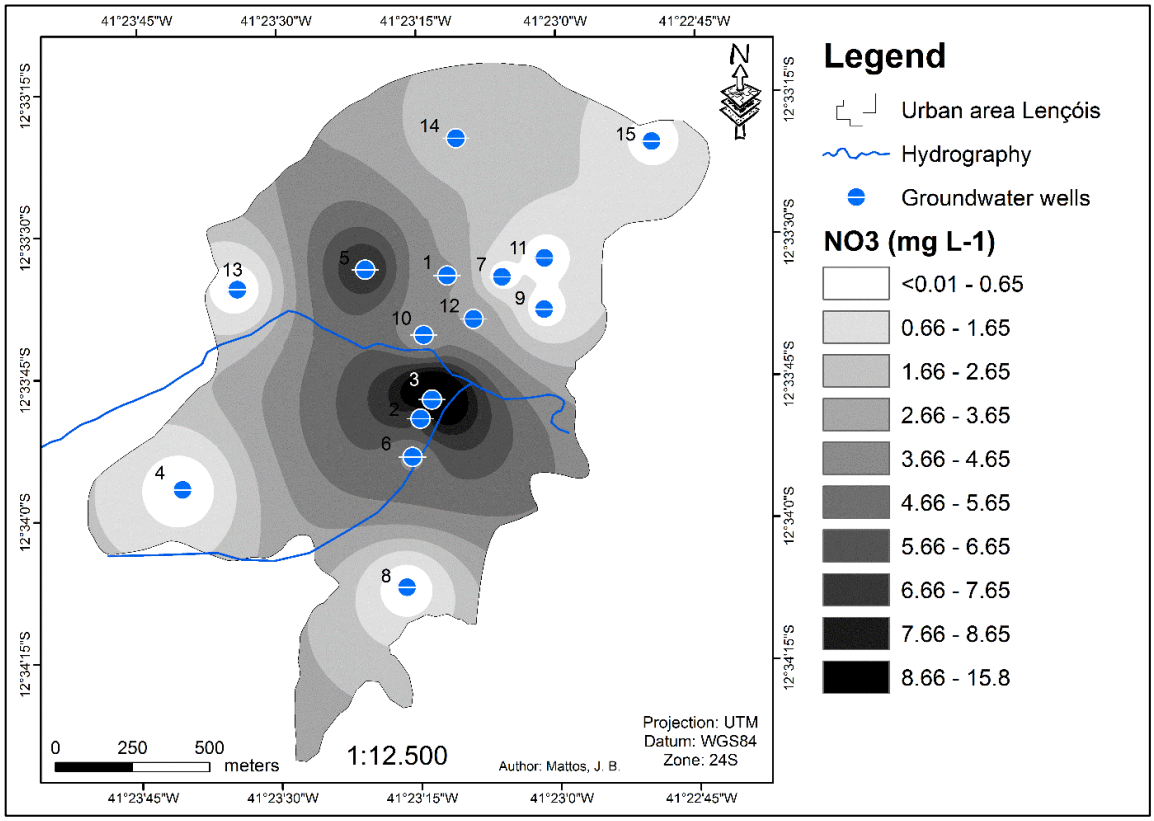


Figure 4 - Map with spatialization of nitrate concentrations in the groundwater of the urban area of Lençóis-BA.

CETESB (2005) takes as a basis for alerts, a value of 5 mg L-1 for nitrate. Using this reference, the waters of points 2, 5 and 6 presented concentrations above 5 mg L-1, above to their respective values being close to mav (maximum value allowed) by ordinance 2914/2011 of the Ministry of Health (Brazil, 2011), which is 10 mg L-1 for nitrate.

Therefore, these points should monitored annually and the sanitary surveillance of the municipality should be aware of the situation. The waters of point 3, extrapolate the mav of the ordinance 2914/2011, as you can see on the map. Therefore, these waters should not destined for human consumption without previous treatment.

It is noted that the further away from the center of the urban area, the lower the presence of nitrate anion dissolved in groundwater, suggesting that in the outlying areas of the city anthropic pressure on groundwater resources is lower, protecting the natural hydrogeochemistry characteristics of the waters . With this approach, one of the possibilities that the municipal management happens to be is the decentralization of some activities, in an attempt to attenuate the pressure exerted on the water resources in the central zone of the city.

The map of Figure 5, also the product of geostatistical interpolation, spatializes the chloride anion concentrations in the groundwater of the urban area of Lençóis, and it is possible to perceive a pattern of similarity with the nitrate concentrations discussed previously. In the absence of microbiological data (E. coli and coliforms) that measure water quality, chloride anion is indicative of anthropogenic contamination. In this bulge, the results presented in this map reinforce the hypothesis of anthropic contamination in the groundwater of the central zone of the city.

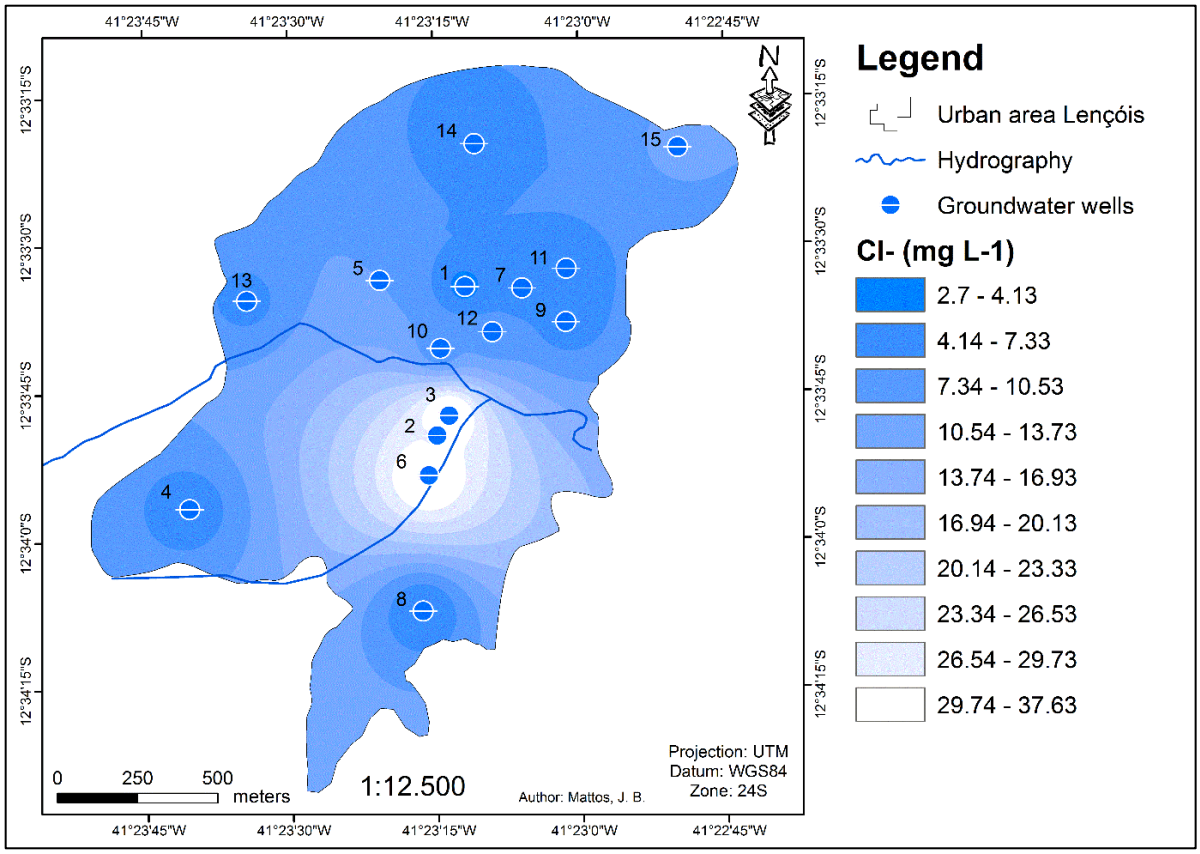


Figure 5 - Map with spatialization of chloride concentrations in the groundwater of the urban area of Lençóis-BA.

With nitrate-like behavior, the chloride can be mobilized to subsurface it through poorly managed wastewater, in addition to other problems described above. In general, chloride concentrations in the waters of the central zone (points 2, 3 and 6) are low, and are below the mav of the Ministry of Health (2914/2011) for chloride that is 200 mg L-1, however, these

waters differ from the others, especially those in the peripheral areas.

Concerning wastewater with low concentrations of chloride, reaffirming with hypotheses of protected areas, with low atmospheric density and less vulnerability to degradation of the water resource. Maintaining good conditions in these areas is essential for a city that depends directly and indirectly on ecotourism as the main socio-economic activity. Management actions in the central area are priorities, no corrective and monitoring measures are necessary, they are also necessary, as peripheral areas are also necessary for the monitoring of management agents, but also to serve as a basis for the search for a balance quality of groundwater.

In the execution of geostatistics in the ArcGis 10 software, the nature of the data indicated that the standard deviation was the best methodological classification to used to spatialize the plumes of dissolved ions in groundwater. The optimal size of the class intervals was 10. Some tests with other methods were done (natural breaks, quantile, geometrical intervals) however, the results were asymmetric and masked.

Like the kernel density, the geostatistics of the IDW interpolator generated results of great value, as it is possible to notice with the maps of the levels of nitrate and chloride. Based on these maps, municipal management can implement policies that improve performance in water and solid waste management in the city, seeking to remedy the hydrochemistry anomalies identified in the groundwater of the zone with traces of contamination.

The best use and utilization of these techniques of geoprocessing depend exclusively on the availability of data, and this requires the elaboration of a methodological road map that contemplates public-private partnerships capable of foment projects of periodic monitoring of surface and groundwater, besides technical qualification of servers designated audiences for project execution. In this way, there will be information to feed a geographic database to use in a geographic information system, being able to generate quick results, of practical application and concrete use by the management.

## 4. Conclusions

With the possible results, conclude that, the use of the geographic information system from the application of the geoprocessing provided results with high potential of subsidy for a management of the water resources. Nitrate and chloride density maps and concentrations of nitrogen and chloride are examples of geoprocessing cartography products (spatial analyzes) that can serve the public power as a legal instrument that supports government to control the use of available water resources in the urban territory.

There are several other possibilities beyond groundwater, which can use geoprocessing methods and be spatially analyzed generating maps with georeferenced thematic information. The use of the Kernel algorithm to zonate the density of the wells of Lençóis has proved to be a powerful tool, generating through mapping a simple, easy to manipulate and survey data product capable of establishing relationships between the exacerbated use or not of groundwater extracted for a particular purpose.

The geostatistics of the IDW method in the GIS was also efficient in the production of spatial data in the maps; however, it requires a consistent project of data collection that can submitted to spatial analysis. In the possession of the necessary information, water resources management can innovate, create and simulate a series of scenarios from the results by the IDW interpolator. In the specific case of the study area of this work, the management team could act immediately in the zoned areas as vulnerable or contaminated, in order to execute actions that address the problems identified by the zoning from geostatistics.

## 5. Acknowledgment

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