

ENVIRONMENTAL MAPPING OF AREAS VULNERABLE TO CONTAMINATION IN THE GUARANI AQUIFER IN THE MUNICIPALITY OF FAXINAL DO SOTURNO-RS, BRAZIL

Diogo Silveira Kersten¹, Fabiano André Marion², Michelli Freitas Mulling Kersten³, Gabriel Oladele Awe⁴, Cassiane Jraj de Melo Victoria Bariani⁵

¹ Universidade Federal do Pampa – UNIPAMPA, Campus Itaquí RS, Brasil.

² Professor Assistente da Universidade Estadual do Oeste do Paraná, PR, Brasil.

³ Uninter / Gestão Ambiental, Brasil.

⁴ Department of Crop, Soil and Environmental Sciences, Faculty of Agricultural Sciences, Ekiti State University, Ado Ekiti, Ekiti State Nigeria.

⁵ Universidade Federal de Santa Maria, UFSM, RS, Brasil.

ABSTRACT

The increasing demand for natural resources, for agricultural use and urban development, could advance towards areas with possible risk of groundwater contamination, because they are not well planned and/or inadequate environmental studies appropriate to a particular condition of use. This situation is related to the natural vulnerability that evaluates soil type, geology, slope and permanent preservation area; identified as environmental conflicts, due to inappropriate activities, in areas with potential risk of groundwater contamination. Thus, the objectives of this study were to conduct a survey of potentially contaminating activities and to relate their areas of influence with the map of natural vulnerability, which defines the interrelationship among soil maps, geology, slope the municipality of Faxinal do Soturno – RS, Brazil to check possible improper soil use. For this purpose, data were collected from wells and a potentiometric surface map was generated from the static level of wells, which allowed the estimation of groundwater flow. In the municipality, potential activities, including cemeteries, hospitals, fuel station, brick kilns and sawmills with potential risk of contamination were identified. With available technical procedures, potentially contaminating activities were identified in areas of medium and high vulnerability, which characterizes the possible risk of contaminating the groundwater in the municipality in question.

Keywords: Geoprocessing; Guarani Aquifer System; groundwater resources; vulnerability of aquifers.

MAPEAMENTO AMBIENTAL DAS ZONAS VULNERÁVEIS À CONTAMINAÇÃO DO AQUIFERO GUARANI NO MUNICÍPIO DE FAXINAL DO SOTURNO-RS, BRASIL

RESUMO

A demanda crescente dos recursos naturais, para o uso agropecuário e para o próprio desenvolvimento urbano, pode estar avançando para áreas de possível contaminação das águas subterrâneas, por não serem planejados e/ou realizados estudos ambientais prévios adequados à determinada condição de uso. Esta situação, relacionada com a vulnerabilidade natural que avalia: tipos de solo, geologia, declividade e área de preservação permanente; identificam-se como conflitos ambientais, devido à realização de atividades inadequadas, em zonas de potencial risco à contaminação das águas subterrâneas. Assim, o presente estudo tem como objetivo, realizar um levantamento das atividades potencialmente contaminantes e, interagir suas áreas de influência com o mapa de vulnerabilidade natural, este definido pela inter-relação de mapas de solo, geologia e pela declividade do município de Faxinal do Soturno – RS, a fim de verificar os possíveis usos inadequados do solo. Para esse propósito, realizou-se o levantamento dos dados dos poços tubulares da localidade, resultando no Mapa de sua superfície potenciométrica, a partir do nível estático dos poços, o que possibilitou estimar o fluxo das águas subterrâneas. Em campo, identificaram-se atividades de potencial risco de contaminação, como: cemitérios, olarias, serrarias, um hospital e um posto de combustível. Após a avaliação de todos os procedimentos técnicos, foram identificadas atividades potencialmente contaminantes em áreas de média e alta vulnerabilidade, o que caracteriza o possível risco de contaminação das águas subterrâneas no município em questão.

Palavras-chave: Geoprocessamento; Sistema Aquífero Guarani; recursos hídricos subterrâneos; vulnerabilidade de aquíferos.

1. INTRODUCTION

Groundwater is vital natural resources for economic and safe supply of water. It is also important for the development of communities in urban and rural areas. Thus, there is a growing demand for groundwater supply for the population. However, aquifers are suffering pollution, in an increasing manner, mainly due to contamination threats caused by urbanization, industrial development, agricultural activities, mineral extraction etc. That as a result of human activities, whether agricultural, industrial and urban, that generate wastes, which are generally leached to deeper soil layers when not adequately controlled and mitigated, forming actual loads of potential groundwater contamination (Foster et al., 2006). For this, Silverio da Silva et al. (2004) state that groundwater should be recognized first as an exhaustible resource, contaminable in short, medium and long term. Since not all water from aquifers are good and fit for consumption. So it is up to the entire population to preserve this resource, avoid indiscriminate disposal of wastes whether in liquid, fueleous or solid form in inappropriate places.

The contamination of groundwater is also attributed to improper use, simply because the populace has no or little knowledge of groundwater resources. Therefore studies become necessary to properly plan and guide the exploitation of groundwater (MARION, 2011).

According to Resolution No. 15 of 11/01/2001 of the National Water Resources Council (CNRH), the aquifer is a hydro-geological body which accumulates and transmits water through its pores, cracks or spaces, resulting from the movement and dissolution of rock materials. The Guarani Aquifer System (SAG) is located within the geological context of the Paraná Sedimentary Basin, extending throughout Brazil, Argentina, Paraguay and Uruguay, representing a typical example of transboundary aquifer. In Brazil, the aquifer is found in the states of Rio Grande do Sul, Santa Catarina, Paraná, São Paulo, Minas Gerais, Goiás and Mato Grosso do Sul (Fuehlmans; Kiang, 2005).

It is important to reiterate that the most vulnerable of this aquifer to contamination are areas where the sandstone outcrops to the soil surface (outcrop), i.e. in the region of direct recharge, where it is exposed and therefore more susceptible to contamination. The vulnerability decreases as the aquifer deepens and under confined conditions (MIGLIORINI; DUARTE; Barros NETA, 2007). In the state of Rio Grande do Sul, much of the outcrops occur in the central region, in the municipality of Faxinal do Soturno – RS, which coincides in part with the Central Depression.

The location of anthropogenic activities in areas adjacent to the aquifer includes the cemeteries, fuel stations, sanitation, industries that produce chemical waste, among others, which are sources of potential contaminant loads. Due to various human activities on land area, the main concern regarding groundwater pollution is the pollution load disposed in the basement associated with urban sanitation installed without sewerage system or septic tanks, septic tanks and latrines, in residential areas with incomplete or no network connection. It should be taken into consideration that there may be small service industries, creating a potentially contaminating load. It should also be recognized that urbanization processes exert a major influence on aquifer recharge mechanisms and the installation of drinking water and/or sewer network is very significant in this regard (FOSTER; HIRATA, 1993).

Another activity that can be found in urban and/or rural areas is the implementation of cemeteries that are potential causes of risks to nature, when installed in inappropriate places, creating a real risk to water resources. The process of decomposition of corpses causes a large proliferation of bacteria, viruses and pathogenic microorganisms

(Pacheco, 2003), thus contaminating groundwater resources through necrochorume infiltration to the aquifer by rainwater infiltration via the pits, or by direct dead body contact with groundwater (Matos, 2001). For this reason, it is of fundamental importance that evaluation of the geological conditions, soil type, hydrogeology, the depth of the groundwater level and the geomorphology of the area be conducted.

The fuel stations for storing highly toxic substances such as diesel oil, fueloline and alcohol were not adequately installed and do not receive the necessary care, thus are environments with potential risk of contamination of underground aquifers. Similarly, poor handling of large volumes of hydrocarbons, which are potentially contaminating chemicals typically stored in underground tanks, leading to contamination of soil and groundwater due to leakage as a result of corrosion of the tanks caused by old age (Kostecki; CALABRESE, 1989; CHEREMISINOFF, 1992; FOSTER et al., 2003).

There are many contaminants originating from diverse agricultural activities, which may reach ground water, such as leaching from the surface, resulting from inadequate soil use and occupation, use of chemical inputs on agricultural soils, and very intensive livestock facilities located near deactivated wells that generate wastes (such as NO_3 , ammonia, coliform, etc), causing potential exposure to pollutants, thus causing contamination, thus necessitating the importance of studies for the understanding and insight into the behavior of the management of soil use and occupation in the city.

Therefore, the classification and identification of potential sources of contamination is an important tool to diagnose the activities that represent the most likely to generate pollutant loads to the aquifer, which will make it possible to establish priorities to define the activities that should be studied and detailed, including monitoring, field investigations and the evolution of the risks to human health (HIRATA, 2002). The National Environmental Council and the National Water Resources Council have regulations for the conservation of underground water sources, and present specific legislation on installation of fuel stations, landfills, cemeteries and other potentially polluting activities, however these rules are not strictly followed.

The vulnerability of aquifer to contamination can be mapped efficiently for possible planning and conservation of natural resources. With such maps, the interaction of the results can be obtained and evaluate potential contaminant loads in order to facilitate the evaluation of the risk of contamination. The term "aquifer contamination risk" means the likelihood that groundwater contaminants will provide a concentration greater than the value established by the WHO (World Health Organization) for human consumption. In Brazil, the quality of drinking water is established by Ordinance of the Ministry of Health No. 518/2004 and supplemented to groundwater by CONAMA Resolution No. 396/2008.

Studies conducted made it possible to identify areas that exhibit vulnerability and in those environments, conflicts were identified as a result of inappropriate activities, which characterizes the risk of environmental contamination. Thus, the objectives of this study were to conduct data collection and environmental characterization (survey of geology, soil types, slopes and static level of wells) in the municipality of Faxinal do Soturno – RS, Brazil and to find activities of potential risk contamination of the aquifer. This design was worked with in situ surveys with GIS application support that interact enabled the points of possible influence of contamination of their natural areas of vulnerability of groundwater in the municipality in question. This action aimed to verify unsuitable land use in vulnerable locations, characterizing risk to groundwater contamination.

2. MATERIALS AND METHODS

2.1 Description of study area

The municipality of Faxinal do Soturno is located in the State's Central region of Rio Grande do Sul (RS), a transition between the Central Depression and Rebordo do Planalto Meridional (rim of the Southern Plateau). It is bounded in the north by the municipality of Nova Palma and Ivorá, in the west by Silveira Martins, in the south São João do Polêsine and in the east by Dona Francisca. According to the Economics and Statistics Foundation-FEE (2011), it has a total population of about 6,669 inhabitants and a total area of 169.9 square kilometers, corresponding to a population density of approximately 39.2 inhabitants/km². She integrates the region of the Fourth Colony of Italian Immigration of the Rio Grande do Sul, composing of nine counties: Agudo, Dona Francisca, Faxinal do Soturno, Ivorá, Nova Palma, Pinhal Grande, Restinga Seca, São João do Polêsine and Silveira Martins.

The Faxinal do Soturno city is situated on the Rebordo do Planalto Meridional, which is composed primarily of effusive basaltic rocks and secondary by sandstone, formed by successive lava flows of the Mesozoic Era. These lavas gave rise to continental effusive rocks, commonly basalts, with dikes and tabular bodies of diabase, whose set is called Serra Geral Formation according to Müller Filho (1970).

The climate of the municipality, according to Köppen's climatic classification, is Cfa, humid subtropical climate, with well distributed rainfall, with an annual average of 1,769 mm; the average temperature of the warmest month is above 22°C and that of the coldest month is around - 3°C (Ayoade, 1986). According to Silverio da Silva et al. (2004), the classic sedimentary rocks belonging to the Central Depression of Rio Grande do Sul State, forming aquifers of porous granular type. As an example, the Botucatu Formation composed of well-selected fine to medium sandstones and, often made up of more than 95% of quartz sand, with a high porosity/permeability ratio. Due to the nature of the grains, it can accumulate large amounts of water, presenting high risk of contamination, because, according to Araújo et al., (1995), the porosity of the Butucatu aquifer oscillates in the order of 17-30%.

Silverio da Silva et al. (2004) reported that the volcanic flow of the Serra Geral Formation as an aquifer of the crystalline fissure type, consisting of massive rocks, having low primary porosity around 1%. But that may have a secondary porosity consists of tonsils, vesicles and loopholes. It could be recalled that acidic rocks present tabular cracks whereas basic rocks are predominantly of vertical cracks, which easily aid the gravitational action of water infiltration.

The natural configuration of the area favours rice cultivation as the river banks are flat, such as the bank of River Jacuí and its tributaries (derived from inland waterway accumulation), as well as wetlands or gently sloping areas. This can be seen in the geological profile of the area which was obtained from the Geological map, and contour lines, with an interval of 20 meters, extracted from the topographic maps of the Army, on a scale of 1:50.000. According to Oliveira (1998), the geological formations show a deviation of 5° in the direction of the center of the Paraná Sedimentary Basin.

According to Machado and Fitz (2001), the municipality of Faxinal do Soturno has four types of soils classified as: red yellow Ultisol (Pva), which has a subsurface horizon more clayey. The ultisols are soils ranging from deep to very deep, ranging from drained to imperfectly drained; hypochromic Alissol (tPA), common in the Central Depression region, medium depth, originating mainly from siltstones and sandstones of medium texture, presenting high acidity in most of the profile; Planossols (SGE) are imperfectly or poorly

drained soils, found in lowland areas, with flat to gently rolling relief. This soil is mostly intended for irrigation agriculture, especially rice cultivation; Chernosols (MTF), are classified as shallow to deep soils, with the surface layer characterized by reasonable amounts of organic matter, which gives it the dark colors.

In addition, there are other types of soils in some regions, giving room for various studies of diverse purposes, whether agricultural, livestock, urban, landscape and environmental.

2.2 Technical Procedures

To establish the areas of environmental risk, considered as environmental occupation responsible, in the municipality of Faxinal do Soturno, surveys and georeferencing were performed on potentially polluting activities which spread over an area of approximately 170.20 square kilometers, where cemeteries, sawmills, wells tubular, fuel station, hospital and pottery were registered.

The procedures used in the first instance include a search of theoretical and methodological reference, such as review of pre-existing bibliographies through books, magazines and articles relevant to the topic in question, as well as visits and interviews with the Secretary of Health and the municipality of Faxinal do Soturno, as well as the Environmental Surveillance sector.

To perform the identification of potential sources of contamination, which can alter the quality of groundwater resources, such as cemeteries, sawmills, wells tubular, fuel station, hospital and pottery, a Global Positioning System (GPS) (Model: Garmin Etrex) was used to register the relative coordinates of the captured places using the Universal Transverse Mercator (UTM) system

With regard to potential sources of contamination, we examined the cemeteries located in urban and rural areas of the municipality, using their respective photographic record. We also conducted interview directly with the owners, managers or staff of fuel stations within the municipality of Faxinal do Soturno.

For the generation of the potentiometric surface map, which allows to infer the likely direction of underground water flow and therefore the dissipation of possible contaminants, the difference between the altitudes of the terrain of the surface of the wells and the deep static level, or in other words, the water level in the state of rest, were calculated

The altimetric dimensions of the land and the coordinates of the wells were obtained using pre-existing SIAFUEL/CPRM data and the interpolation of the contour lines of topographic maps of the Army. This relationship allowed an estimation of the height of the water column in relation to the vertical datum, sea level of the Torres-RS tide gauge, and reference to the horizontal datum of Córrego Alegre, as used by the army to carry out the cartographic mapping which was used as the basis of this study. Thus, twelve (12) registered wells in SIAFUEL / CPRM and sixteen (16) in the field were used.

The parameters to be represented cartographically and by Universal Transverse Mercator coordinates (UTM) were tabulated in an Excel spreadsheet, where interpolation was carried out to generate the potentiometric surface map. For this, we used the ordinary Kriging method, because this method showed the best results compared to other tested methods (Inverse Distance Square, Minimum Bend and Regression Polynomial). Also included are the indicative vectors of the flow direction of groundwater, which most times do not match the flow of surface water.

In the survey, the occurrence and the type of activities with potential contamination risks were observed. Combining these, the conditions of the wells were assessed and information, such as static level (UTM coordinates), the altimeter quota and the existence of well protection were collected. To measure the static level, a sound level meter (Model: Jaciri) assigned by the Hydrogeology Laboratory – UFSM was used.

After the survey, we proceeded to the definition of areas of influence, represented by buffers which were generated using ArcMap 9.3 software. The map of the areas of influence of potentially polluting activities was exported in a “tiff” file format. In SagaGis (2007 version) software, the “tiff” files were converted to the “rst” file format and related with the map of natural vulnerability of groundwater in order to identify potential differences caused by potentially polluting activities in places where groundwater may have vulnerability.

The natural vulnerability mapping of groundwater has been carried out by Kersten (2009), which hierarchized from the natural ground conditions, the different conditions of natural vulnerability of the aquifers in the municipality, thus providing the basis for the realization of this work. Figure 1 illustrates the variables used and their respective weights of environmental importance.

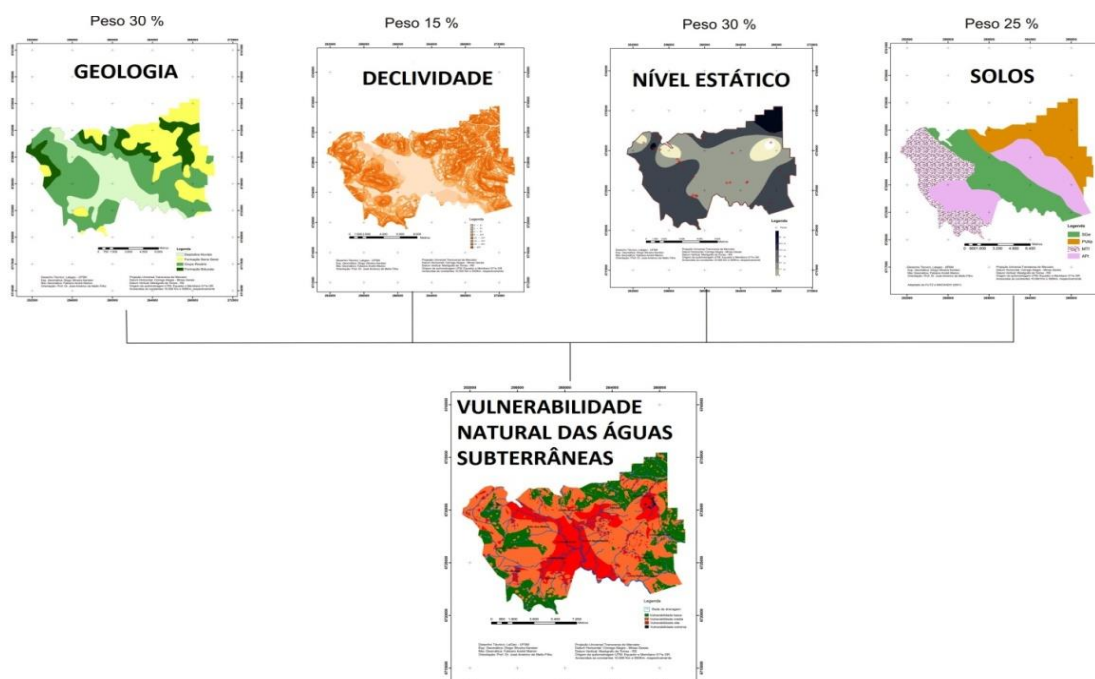


Figure 1. The various maps used and their relative importance by weights in obtaining the map of natural vulnerability of groundwater in the municipality of Faxinal do Soturno – RS, Brazil. Adapted from: Kersten (2009)

3. RESULTS AND DISCUSSION

The characterization of pollution risk ground water consists of the association and interaction of natural vulnerability of the aquifer with the activities on the surface or within the subsurface. One can configure a highly vulnerable, but without risk of contamination, if there is no significant pollutant load, or vice versa, since it is the type, intensity, shape, and time of the disposition of activities that determine the actual situation of risk which the aquifer and, more precisely, water resources are subjected to.

Among the sources of contamination, fuel stations require more attention because they use non-biodegradable chemicals and considering the time of installation, the age of the tank and its contact with the soil, these pollutant agents can easily reach the groundwater resources, depending on the degree of vulnerability of the area.

Based on this and according to the natural vulnerability map of groundwater prepared by Kersten (2009), the locations where fuel stations are found in the city of Faxinal do Soturno-RS is considered as average vulnerability. In addition, the stations found within the urban area of the municipality and as also seen in the field have car wash which uses the car wash system, thus increases the pollution potential.

Although the position of the stations in the area is of medium vulnerability, however there could be contamination, if, for example, there is a leaking storage tank. According to the owners/managers of these stations, they carry out adequate monitoring of surrounding wells to detect the existence of fuel leaks.

The hospitals, although small, have potentially contaminating activities, because in these sites, there are surgeries and treatments of infectious diseases although the management obliged to using water of excellent quality, according to the guidelines of MS Ordinance No. 518/2004, which enforces the need for conservation of groundwater quality in the city.

Solid waste, when improperly released on the surface, as well as cemeteries, represent a significant source of contamination of both surface- and groundwater. Therefore, the choice of the most appropriate way is necessary for collection and discharge, with a view to minimizing environmental impacts, specifically the surface and ground water resources.

For the sawmills, there are activities with machines ranging from medium to large scale and for the operation of such equipment, fossil fuels are used. In the same vein, the potteries use heavy machinery for the elaboration of parts for the fabrication of large kilns, which necessitates the need to service and supply these machines with fossil fuel and lubricants. Thus if proper handling and care required for the fuel and wastes generated are not taken, the likely result will be contamination of soil and water resources.

Table 1 shows the potentially contaminating activities identified in field work conducted within the municipality of Faxinal do Soturno, showing the form of dispersion and the possible radius of influence.

Table 1 - Potentially contaminating activities identified in the municipality of Faxinal do Soturno - RS, Brazil and the possible radius of influence

Activities	Form of dispersion	Radius of Influence
Cemeteries	Point	200 m
Municipal Hospital	Point	100 m
Fuel stations	Point	80 m
Sawmills	Point	80 m
Potteries	Point	80 m

To understand the behaviour of groundwater flow, the general direction of its flow was inferred. Through the interpolation of 28 wells (in red colour), the potentiometric surface map was generated (Figure 2), which allows the prediction of the dispersion of possible

contaminants, to see if they reach groundwater. Most times, the groundwater flow does not match the flow of surface waters. Thus, it is possible to perform an analysis between the potentially polluting activities (cemeteries, sawmills, potteries, fuel stations and hospital) that have been georeferenced and the direction of groundwater flow.

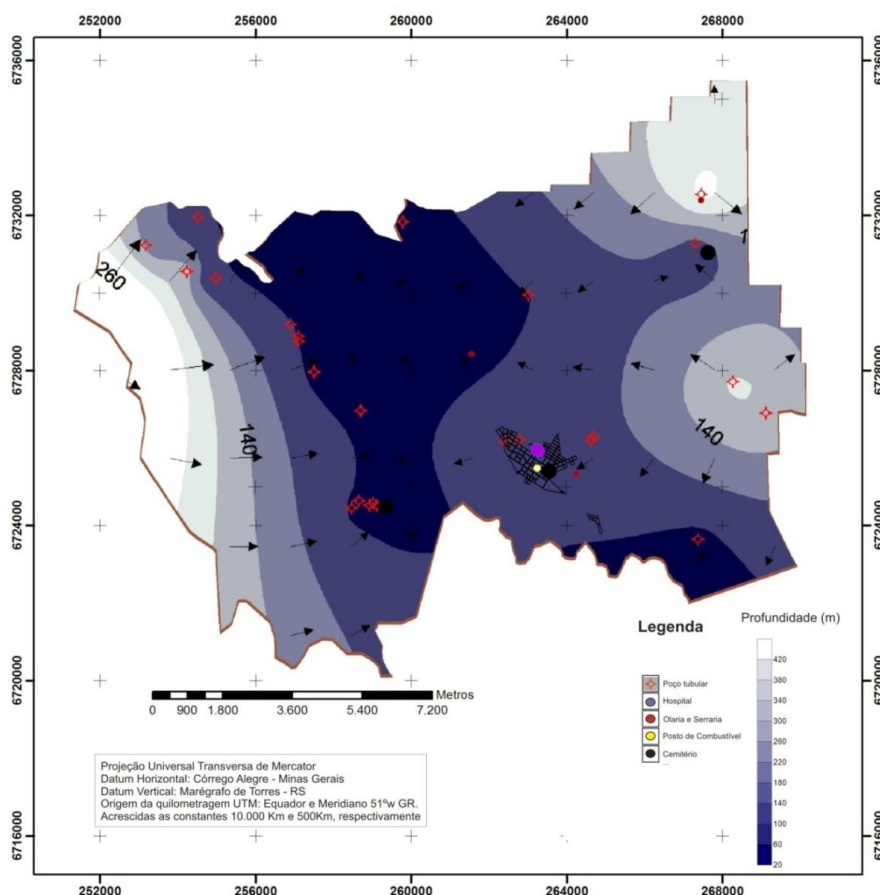


Figure 2. The potentiometric surface map. Source: Kersten (2009).

Cemeteries were found in urban and rural areas, and from their UTM coordinates, a buffer with a circular radius of 200 m was generated, which is an average area of possible risk of contamination that can occur through necrochorume of cemeteries. These are likely to alter the quality of groundwater, and besides being close to tube wells, the groundwater flow converge to the same, as can be seen in Figure 3 (black dots).

Sawmills and potteries were located in the cartogram as circles in which buffers were equally inserted in turn of 80 meters radius, this value was defined where activities that generate chemical waste such as oils and fossil fuel for lubrication and operation of machinery, which are subject to groundwater contamination and other water resources, as identified by red dots in Figure 3.

Potentially polluting activities are also found within the urban perimeter, as observed from the hospitals and fuel stations. The hospital is a place with presupposed potentially contaminating activities for conducting surgeries, hospitalization of patients with infectious diseases as well as maintenance of equipment and generation of hospital residues. The constant realization of cleaning, sanitation and disposal of infected materials and medicines, often in inadequate manner generate effluents and the disposal in the environment without

treatment may cause serious impacts. Thus, we defined a radius of 100 meters as the area of possible influence of contamination of groundwater.

The georeferenced fuel stations, which store amount of fossil fuels to meet the demand of the populace, were found in the urban zone of the municipality. These stations carry out car cleaning services, using car wash system. The water used for cleaning at the stations' car wash can be contaminated with lubricating oils and fuels, thus enhancing the contamination by infiltration as the contaminants leach from the surface soil till deeper layers, and finally reaching the groundwater. For this, a radius of 80 meters was defined as the area of possible influence of contamination of groundwater, identified by yellow colour in Figure 3.

With these data, we performed an analysis of the interaction between the areas of influence of potentially contaminating activities and the map of natural vulnerability of underground waters, prepared by Kersten (2009) (Figure 3). From this map, it appears that most of potentially polluting activities fall under middle and high vulnerability, indicating an imminent risk of contamination in those sites.

The evaluation and integration of thematic maps allowed to identify areas that may pose imminent risk to public health, and it is recommended that conservation practices be put in place according to Brazilian legislation and ethics on public administration.

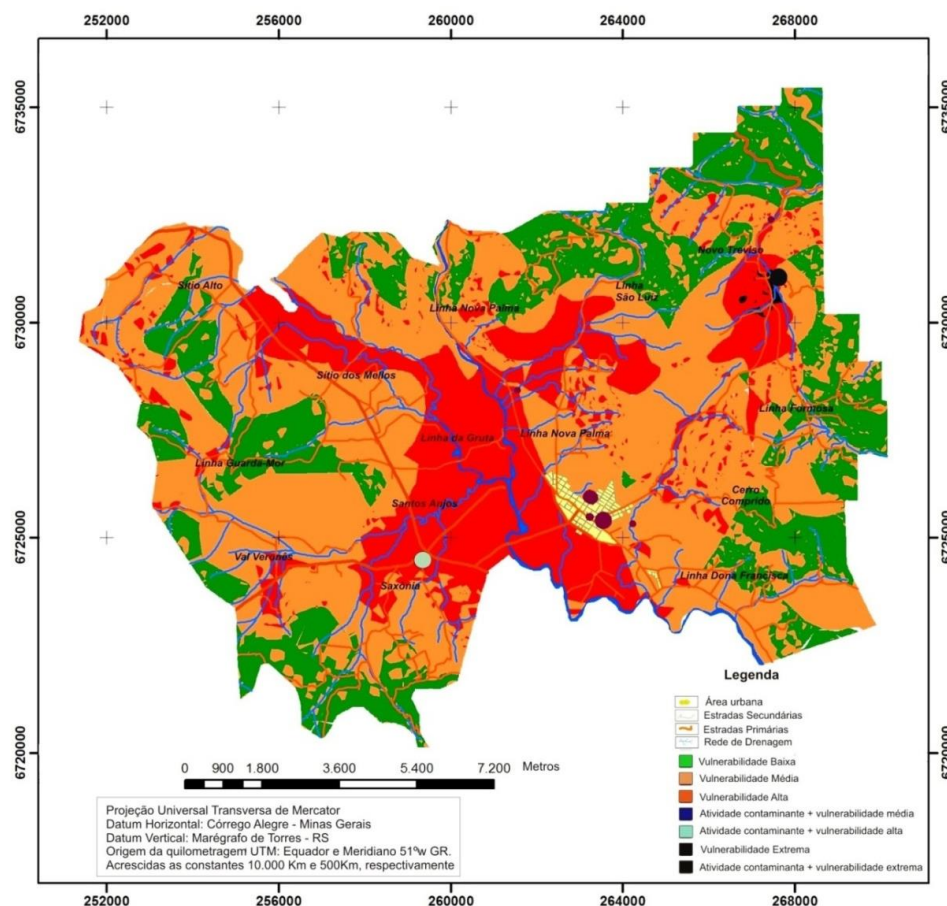


Figure 3. Natural vulnerability map of groundwater contaminants activities.

4. CONCLUSIONS

The contamination of surface and groundwater resources is becoming a growing concern, especially in large urban centers, where there is great demand for its use. In this context, the drilling of wells increases, which are often implemented without an environmental permit as provided in the State Environmental Law of Rio Grande do Sul (Art. 134 and 136), posing risk of contamination. Therefore, the municipal governments should maintain current records of wells.

The study of natural vulnerability of groundwater carried out in the municipality of Faxinal do Soturno-RS was developed in partnership with the Department of Municipal Health Surveillance, showing further advance in the knowledge of the potentials and risks of use of this natural resource. Once contaminated, decontamination is difficult and costly, and even without significant vulnerability, an aquifer, if exposed to successive contaminant loads, is vulnerable to contamination. Thus, studies such as this could serve as a warning to both the public and concerned agencies as regard the need for the conservation of water supplies.

A better characterization of the risk of groundwater contamination is a function of the association and interaction between natural vulnerability of the aquifer and the activities on the soil surface or within the subsurface. Therefore, groundwater vulnerability studies is extremely important.

Although the municipal may adopt preventive measures for both the protection of possible events, such as expansion and urban occupation, that could contaminate the aquifer, we suggest that through its Strategic Plan, the municipality must indicate the allocation of potentially contaminating activities in low-vulnerability areas where the terrain can mitigate possible contamination, thus ensuring the rational use of the territory and thus contribute to guarantee the quality of natural resources for present and future generations, as specified in the State Environmental Code - State Law No. 11,520 of 03/08/2000.

It is noteworthy that the urban area of Faxinal do Soturno showed medium vulnerability as observed in this study, however there were activities of potential contaminants such as the cemetery, hospitals and fuel stations.

The results obtained in this study are important for municipal planning, as they provide insight to environmental management.

It is recommended that study be expanded, comprising more wells as well as wider potentially polluting activities in order to ensure a more detailed understanding and meet the sanitary requirements according to State and Federal regulations governing the construction and development of new projects in the municipality of Faxinal do Soturno - RS.

5. REFERENCES

AYOADE, J. O. **Introdução à Climatologia para os Trópicos**. Rio de Janeiro: Bertrand Brasil, 1986.

ARAÚJO, L. M.; FRANÇA, A. B.; POTER, P. E. **Aquífero gigante do MERCOSUL no Brasil, Argentina, Uruguai e Paraguai; mapas hidrogeológico das formações Botucatu, Pirambóia,**

Rosário do sul, Buena vista, Misiones e Tacaurémbo. Mapas. Curitiba: UFPR / PETROBRÁS, 1995, 16 p.

BRASIL. MS. MINISTÉRIO DA SAÚDE. **Portaria N° 518, de 25 de março de 2004.** Atualizam as disposições da Portaria N° 1469, de 29 de dezembro de 2000. Brasília, 2004. Disponível em: <http://dtr2001.saude.gov.br/sas/PORTARIAS/Port2004/GM/GM-518.htm>.

CONAMA. CONSELHO NACIONAL DO MEIO AMBIENTE. **Resolução nº 273, de 29 de novembro de 2000.** Estabelecem diretrizes para o licenciamento ambiental de postos de combustíveis e serviços e dispõe sobre a prevenção e controle da poluição. Publicada no DOU no 5, de 8 de janeiro de 2001, Seção 1, páginas 20-23.

CONAMA. CONSELHO NACIONAL DO MEIO AMBIENTE. **Resolução nº 396, de 3 de abril de 2008.** Publicada no DOU nº 066, em 07/04/2008.

CNRH. CONSELHO NACIONAL DE RECURSOS HÍDRICOS. **Diário Oficial da República Federativa do Brasil.** Resolução n. 15 de 11 de janeiro de 2001. Poder Executivo, Brasília, DF, 2001. 3p.

CPRM - Companhia de Pesquisa e Recursos Minerais. Serviço Geológico do Brasil. **SIAFUEL.** Disponível em:

< <http://www.cprm.gov.br/publique/cgi/cgilua.exe/sys/start.htm?sid=59> >. Acesso em 24 maio 2009.

FEE - Fundação de Economia e Estatística, Governo do Estado do Rio Grande do Sul. **Resumo estatístico** Disponível em:

http://www.fee.tche.br/sitefee/pt/content/resumo/pg_municipios_detalhe.php?municipio=Faxinal+do+Soturno. Acesso em 01 nov. 2012

FOSTER, S. et al. **Protección de la Calidad Del Agua Subterránea.** Washington: Groundwater Management Advisory Team, 2003.

FOSTER, S. et al. Proteção da qualidade da água subterrânea: um guia para empresas de abastecimento de água, órgãos municipais e agências ambientais. São Paulo: SERVIMAR, 2006. 114 p.

FOSTER, S.; HIRATA, R. C. A. **Determinação de riscos de contaminação das águas subterrâneas:** um método baseado em dados existentes. São Paulo: Instituto Geológico, 1993. 87 p. (Boletim, n. 10).

FUELTMANS, D.; KIANG, C. H. Avaliação da hidrogeologia e hidroquímica do Sistema Aquífero Guarani (SAG) no estado de Mato Grosso do Sul. **Águas Subterrâneas**, v. 19, n. 1, p. 35-48, jan./abr. 2005.

HIRATA, R. C. A. Carga contaminante y peligros a las aguas subterráneas, **Revista Latino-Americana de Hidrogeologia**, n.2, 2002. p. 81-90.

KERSTEN, D. S. **Avaliação ambiental por geoprocessamento como base ao Plano Diretor Municipal de Faxinal do Soturno – RS**. Dissertação (Mestrado em Geomática) - Universidade Federal de Santa Maria, Santa Maria. 2009. 127 f.

MACHADO, M. L. L.; FITZ, P. R. **Mapa de reconhecimento dos solos do Estado do Rio Grande do Sul: Geoprocessamento**. Porto Alegre: Divisão Técnica EMATER-RS, 2001.

MATOS, B. A. **Avaliação da ocorrência e do transporte de micro-organismos no aquífero freático do cemitério de Vila Nova Cachoeirinha, município de São Paulo**. 2001. 172 f. Tese (Doutorado em Recursos Minerais e Hidrogeologia) - Universidade de São Paulo, São Paulo. 2001.

MARION, F. A. Águas subterrâneas, atividades potencialmente contaminantes e o aporte do geoprocessamento na definição de conflitos. **Geoambiente online**, Jataí, n17, p.31-48, jul/dez. 2011.

MIGLIORINI, R. B.; DUARTE, U. ; BARROS NETA, M. A. P. (org.). **Educação Ambiental para a preservação do Aquífero Guarani na Região do Planalto dos Guimarães**. Disponível em: < <http://www.abas.org/> >. Acesso em: 20 jan. 2012.

MÜLLER FILHO, I. L. **Notas para o Estudo da Geomorfologia do Rio Grande do Sul, Brasil**. Santa Maria: Imprensa Universitária, 1970.

OLIVEIRA, A. M. S. et al. **Geologia de engenharia**. São Paulo: Associação Brasileira de Geologia de Engenharia, 1998, 573 p.

PACHECO, A. (Coord.). **Mapa das fontes potenciais de contaminação do município de Atibaia: texto explicativo**. São Paulo: USP, 2003.

RIO GRANDE DO SUL. Secretaria do Meio Ambiente. **Código estadual do meio ambiente**. Lei estadual nº 11.520 de 03.08.2000. Porto Alegre: SEMA/SEMA/FZB, 2000. 107 p.

SILVÉRIO DA SILVA, J. L.; MAZIERO, L.; SANTOS, E. F. dos. Impactos da atividade humana sobre o solo: aquíferos. In: AZEVEDO, A. C.; DALMOLIN, R. S. D.; PEDRON, F. de A. (Eds.) **Solos & Ambiente - I Fórum**. Santa Maria: Pallotti, 2004. p. 145-167.