Baseline of the outcropping Guarani Aquifer System in Rivera and Tacuarembó, Uruguay: Piezometry and Vulnerability

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Línea de Base del Sistema Acuífero Guaraní aflorante en Rivera y Tacuarembó, Uruguay: Piezometría y Vulnerabilidad

Linha de base do Sistema Aqüífero Guarani aflorante em Rivera e Tacuarembó, Uruguai: Piezometria e Vulnerabilidade

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Abstract: The piezometric, water table and vulnerability baseline of the outcropping Guaraní Aquifer System (GAS) in the departments of Rivera and Tacuarembó (Uruguay) is presented. The flow network and chemical composition are essential to understanding underground dynamics and identifying recharge and discharge zones, preferential flow directions, and determining hydraulic gradients. It is essential to analyze its evolution in time and space from the baseline, for the management and protection of the resource. Vulnerability was determined by applying the GOD and EKv methods, obtaining similar results, with areas of high and moderate vulnerability in most of the studied area. The risk of groundwater contamination was determined using the method of Foster & Hirata[34], obtaining high risk for potentially polluting loads from lack of sanitation, solid household waste, irregular settlements, and gas stations, in areas of moderate and high vulnerability. Industrial and mining activity and a cemetery represent a moderate risk in most cases. Having maps of vulnerability and risk of groundwater contamination is essential to identify the most vulnerable areas and implement detailed study, control, and protection tools aimed at conserving and mitigating impacts on GAS.

Keywords: baseline, Guaraní Aquifer System, vulnerability, contamination risk.

Resumen: Se presenta la línea de base piezométrica, freática y de vulnerabilidad del Sistema Acuífero Guaraní aflorante (SAGa) en los departamentos de Rivera y Tacuarembó, Uruguay. La red de flujo y la composición química son esenciales para comprender la dinámica subterránea e identificar zonas de recarga y descarga, direcciones de flujo preferenciales y determinar gradientes hidráulicos. Analizar su evolución en el tiempo y en el espacio a partir de la línea de base es esencial para la gestión y la protección del recurso. La vulnerabilidad se determinó aplicando los métodos GOD y EKv, obteniendo resultados similares, con áreas de vulnerabilidad alta y moderada en la mayor parte del área estudiada. El riesgo a la contaminación del agua subterránea se determinó utilizando el método de Foster & Hirata[34], obteniéndose riesgo alto para cargas potencialmente contaminantes provenientes de falta de saneamiento, residuos sólidos domiciliarios, asentamientos irregulares y estaciones de servicio, en zonas de vulnerabilidad moderada y alta. La actividad industrial y minera y el cementerio representan un riesgo moderado en la mayoría de los casos. Disponer de mapas de vulnerabilidad y riesgo de contaminación del agua subterránea es imprescindible para identificar las zonas más vulnerables e implementar herramientas de estudio detallado, control y protección que tiendan a la conservación y la mitigación de impactos en el SAGa.

Palabras clave: línea de base, Sistema Acuífero Guaraní, vulnerabilidad, riesgo de contaminación.

Resumo: É apresentada a linha de base piezométrica, do lençol freático e de vulnerabilidade do Sistema Aquífero Guarani aflorante (SAGa) nos departamentos de Rivera e Tacuarembó, Uruguai. A rede de fluxo e a composição química são essenciais para entender a dinâmica subterrânea e identificar zonas de recarga e descarga, direções preferenciais de fluxo e determinar gradientes hidráulicos. Analisar sua evolução no tempo e no espaço a partir da linha de base é essencial para o gerenciamento e proteção do recurso. A vulnerabilidade foi determinada aplicando-se os métodos GOD e EKv, obtendo-se resultados semelhantes, com áreas de vulnerabilidade alta e moderada na maior parte da área estudada. O risco de contaminação dos lençóis freáticos foi determinado pelo método de Foster & Hirata[34], obtendo-se alto risco para cargas potencialmente poluidoras por falta de saneamento, resíduos sólidos domiciliares, assentamentos irregulares e postos de serviços, em áreas de vulnerabilidade moderada e alta. A atividade industrial e de mineração e o cemitério representam um risco moderado na maioria dos casos. Ter mapas de vulnerabilidade e risco de contaminação de lençóis freáticos é essencial para identificar as áreas mais vulneráveis e implementar estudos detalhados, ferramentas de controle e proteção destinadas a conservar e mitigar impactos no SAGa.

Palavras-chave: linha de base, Systema Aqüífero Guarani, vulnerabilidade, risco de contaminação.

1. Introduction

The Guaraní Aquifer System (GAS) is the main groundwater source in the north of the country. It supplies the city of Rivera, small towns and rural inhabitants for human consumption, in addition to being exploited for irrigation and livestock, favoring and promoting the socio-economic development of the region.

Montaño and others[1][2][3] define GAS as a hydrogeological system consisting of a hydraulically connected Permo-Jurassic-age sedimentary sequence. This sedimentary sequence is integrated from base to ceiling, by the following formations: Yaguarí - Buena Vista[4] and Grupo Batoví Dorado[5][6] (Cuchilla Ombú[4], Tacuarembó and Rivera[4]). The petrography of the outcropping formations in Rivera and Tacuarembó and the stratigraphy of the GAS can be found in the publication *Sedimentary Petrography of the Outcropping Formations of the Guarani Aquifer System and Hydrogeological Implications*[7],that accompanies this study and is part of the dissemination of the fundamental results for the knowledge and subsequent advance of the outcropping Guarani Aquifer System in the area of Rivera and Tacuarembó.

Water supply in the city of Rivera came entirely from surface water (Cuñapirú stream), until 1960. As of that date, the State Sanitary Works (OSE by its Spanish acronym) started building the first supply wells continuing to the present. Currently, the largest source of supply in the city of Rivera is groundwater, with 80% coverage (2021 personal communication with P. Decoud; not referenced). This change in the source of supply was mainly due to the economic viability of the exploitation of groundwater resources and their quality, in addition to the reliability of the water resource, mainly in times of drought. On the contrary, the city of Tacuarembó, second in number of inhabitants of the GAS outcropping area, is 100% supplied with surface water from the Tacuarembó River (2021 personal communication with P. Decoud; not referenced), due to the abundance of this resource and the low flows obtained in the groundwater catchments of the Tacuarembó aquifer unit. Currently, approximately 14 million m^3/year are extracted from the Guaraní Aquifer System in Uruguay and from the outcropping area alone. About 10 million m^3/year are used for drinking water in urban areas and small towns, while about 4 million m^3/year are used for human consumption and irrigation in rural areas. These numbers show the importance of this system in the human development of the region, being essential, therefore, to have specific management and protection plans in the outcropping area, where the system is more vulnerable and presents the greatest risks of contamination. Assessing vulnerability is therefore essential to determine the contamination risk and establish land uses that tend to preserve the resource. In Uruguay, examples of vulnerability maps that tend to conserve the underground water resource were made for the Raigón Aquifer (Vulnerability chart of the Raigón Aquifer[(8)(9)]), for the Mercedes Aquifer (Vulnerability of the Mercedes aquifer[(10)]), for the Chuy Aquifer (Vulnerability of the Chuy Aquifer[(11)]) and the fractured carbonate aquifers of the eastern sector of the country (Vulnerability of fractured carbonate aquifers[(12)]).

There is no doubt that the GAS must be managed and, in this regard and in search of efficient planning, the Integrated Management Plan of the Guarani Aquifer is currently being prepared, which includes programs of the National Water Plan and possible projects to develop aiming to manage, preserve and mitigate possible impacts that deteriorate and contaminate groundwater in the outcropping area or recharge area and the confined area of the GAS.

It is essential to have a baseline in the Integrated Management Plan that is being developed. For these reasons, this research aims to present the first results that constitute the baseline of the outcropping GAS, in terms of piezometry, water table depth and vulnerability, as well as the risk of groundwater contamination. The location of the study area is shown in Fig.1 and corresponds to the geological map of the GAS outcropping area in Uruguay.

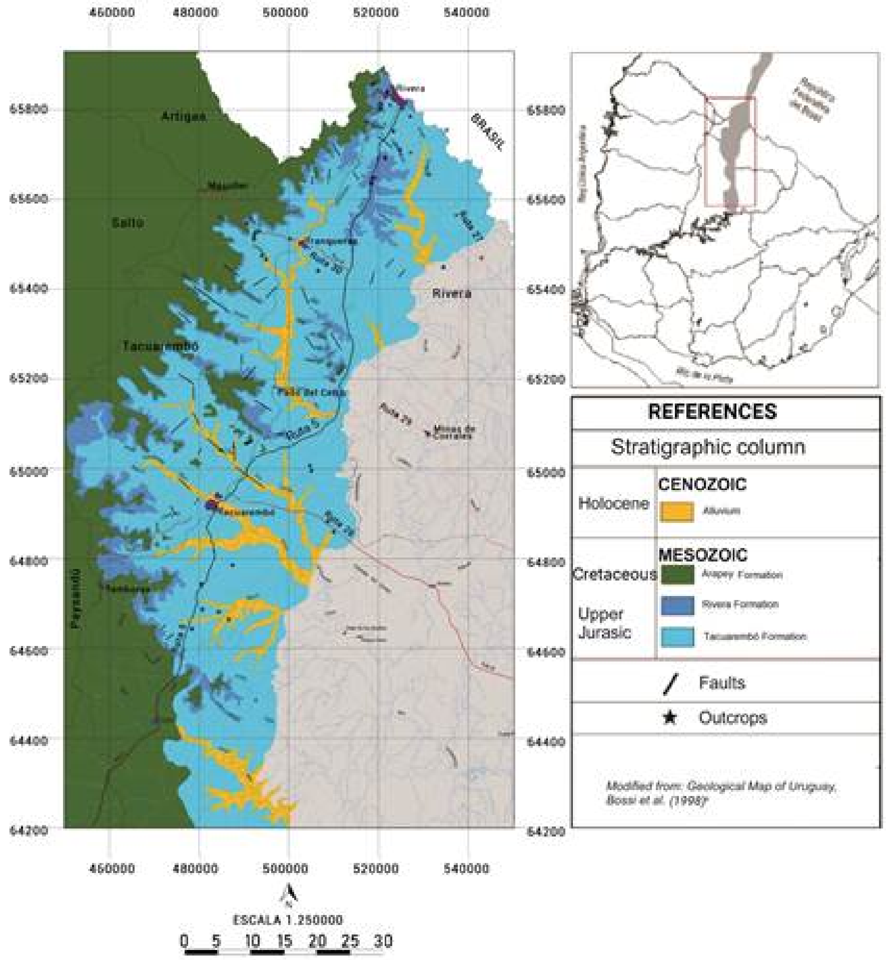


FIGURE 1
Geological Map of the outcropping area of the Guarani Aquifer System in the departments of Rivera and Tacuarembó, Uruguay

2. Material and methods

All data were collected within the framework of the Project Guarani Fund of Universities entitled *Vulnerability and Hydrogeological Risk of the Guarani Aquifer System in the Outcropping Area of Rivera, Uruguay*[13], with funds donated by the Dutch Cooperation Program (Bank Netherlands Partnership), within the Project for the Environmental Protection and Sustainable Development of the Guarani Aquifer System. The first doctoral thesis in the outcropping area of the GAS, entitled *Hydrogeological Research of the Guarani Aquifer in the outcropping area of Rivera and Tacuarembó, Uruguay*[14], also developed from the report corresponding to the project results.

The field-obtained information was entered into a Geographic Information System (GIS), developed specifically for the outcropping area of the GAS which allows the processing of information and the generation of thematic maps. The basic cartography (1:250,000) was developed in Arcview format and covered a total of 16 topographic sheets (1:50,000) of the Cartographic Plan of the Military Geographic Service (MGS) of the República Oriental del Uruguay (Sheets: Rivera, Paso de Ataques, Tranqueras, Cuñapirú, Minas de Corrales, Cuchilla del Ombú, Los Novillos, La Hilera, Arroyo de Clara, Masoller, La Palma, Paso del Cerro, Bañado de Rocha, Tacuarembó, Batoví, Curtina)[15][16][17][18][19][20][21][22][23][24][25]

[26][27][28][29][30]. Digitization included hydrographic networks, major towns and cities, departmental and international borders, national routes, and secondary roads.

Wells, outcrops, and surveyed points were added to the mapping using Gauss Krüger projection. The fundamental geological survey for the analysis of vulnerability and risk of groundwater contamination was carried out by identifying and delimiting the main geological units, differentiating lithofacies, raising profiles and taking representative samples, in order to prepare the geological map of the region at a scale of 1:250,000, which is reproduced in Fig. 1. The well location map (Fig. 2) was generated from the census of wells and water points, fundamental for the preparation of the piezometric map and the water table depth map (Fig. 3 and 4). The well census consisted of obtaining hydraulic information, groundwater use, measurements of the total depth of the well, static level, dynamic level, suction level and flow rate, among others. Geographical coordinates were obtained with a Trimble data collector, with an error of up to 3 m, and the height above sea level (asl) was obtained from the topographic elevations, represented in the topographic sheets of the MGS.

Static levels were measured with a millimeter-graduated electrical probe, considering an error not greater than a centimeter. Based on the scale (1:250,000), the regional field survey comprised a total of 119 perforations, which provided a density of 1 well every 50 km. (Fig. 2). A more detailed survey was carried out in the city of Rivera at a scale of 1:50,000, which included the OSE catchment wells. The survey included about 140 wells in total. The flow network, essential for understanding underground dynamics (identifying recharge and discharge zones, preferential flow directions and determining hydraulic gradients), was constructed from the values of the hydraulic dimensions (difference between the topographic level and the depth of the water level measured in the well).

The piezometric map was made using spatial data interpolation (ArcGIS) and then manually corrected, according to topography and surface drainage network. According to the scale of work and the distribution of the wells, an equidistance of 10 m was chosen, which allowed achieving an adequate definition of the piezometric morphology. The Water Table Depth Map of the outcropping GAS was elaborated to know the distribution of the water depth in the studied area, which is reproduced in Fig. 4.

The underground flow rates were calculated considering the actual flow rate (v*) using the equation $v^{*}=v/me$, with v being the Darcy velocity or simply flow rate, and m., the effective porosity[31]. Effective porosity was determined using the granulometric correlation method (Briggs and Shantz formula)[31], where the effective porosity is the total porosity minus the specific retention (mr), $m_r = 0.03\ (\%sand) + 0.35\ (\%silt) + 1.65\ (\%clay)$. The value of the total porosity was determined by optical methods, from thin sheets impregnated with blue epoxy resin, made in the Cutting Laboratory of the Institute of Geochronology and Isotopic Geology (CONICET-University of Buenos Aires). The method is based on the counting of the empty spaces through the petrographic microscope, and subsequent use of the *Phase Expert* software, of the Institute of Geological Sciences of the Science College.

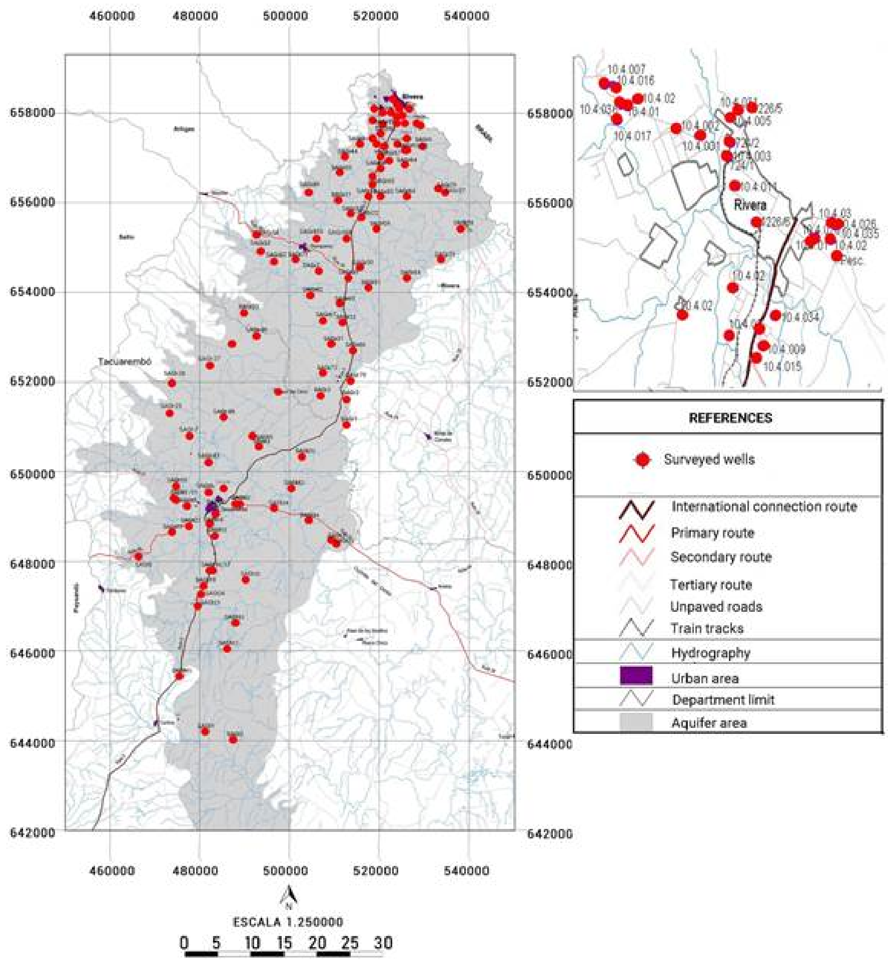


FIGURE 2
Well location map of the outcropping area of the Guarani Aquifer System in the departments of Rivera and Tacuarembó, Uruguay

The chemical composition of groundwater, which was analyzed together with piezometry, was determined in the laboratory of the National Directorate of Nuclear Technology (DINATEN by its Spanish acronym), belonging to the Ministry of Industry, Energy and Mining. The physico-chemical parameters were measured *in situ*, using pH and conductivity probe (Horiba). Chemical data analysis was performed using Waterloo Hydrogeologic's AquaChem *software*.

The selected methods to determine vulnerability and based on aquifer characteristics were the GOD method(32)and the method for free aquifers EKv(33) (Fig. 5 and 6). GOD bases its method on the assignment of indices (0 to 1) to three variables, whose acronym and definition are: **G**: Groundwater occurrence, **O**: Overall Aquifer Class, **D**: Depth to Groundwater Table or Strike. The three indices are multiplied, resulting in a value that can vary between 0 and 1 and will determine the vulnerability of the aquifer. The vulnerability classification ends by entering this last number in the output of the method ranging from: 0 to 0.1 minimum vulnerability, 0.1 to 0.3 low vulnerability, 0.3 to 0.5 moderate vulnerability, 0.5 to 0.7 high vulnerability, and 0.7 to 1 extreme vulnerability (Fig. 5). The Ekv method(33) is the only existing method developed exclusively for free to semi-confined aquifers; the methodology considers a classification based on the water table depth (**E**) and the vertical permeability of the subsaturated zone (**Kv**). Each of the variables is assigned an index ranging from 1 (least vulnerable) to 5 (most vulnerable), which together represent the vulnerability index with extremes of 2 and 10. Fig. 6 shows the mechanism for calculating the different indices, the index for the water table depth (E), and the index for the vertical permeability of the subsaturated zone (Kv). The latter considers the following lithologies: Index 5 corresponds to vertical permeabilities (Kv) of 50 to 500 m/day (medium and coarse sand, sandy gravel, and gravel). Index 4, vertical permeabilities (Kv) from 1 to 50 m/day (very fine to silty sand, fine sand, and medium to coarse sand). Index 3, vertical permeabilities (Kv) from 0.01 to 1 m/day (silt and sandy silt). Index 2, vertical permeabilities (Kv) of 1.10^{-3} at 0.01 m/day (silt and clayey silt). Index 1, vertical permeabilities (Kv) < 0.001 m/day (clay and silty clay). The vulnerability diagram is reproduced at the end and it is the sum of the 2 variables considered, **E + Kv**, being categorized as: low vulnerability between 2 and 4, medium vulnerability between 5 and 7, and high vulnerability between 8 and 10.

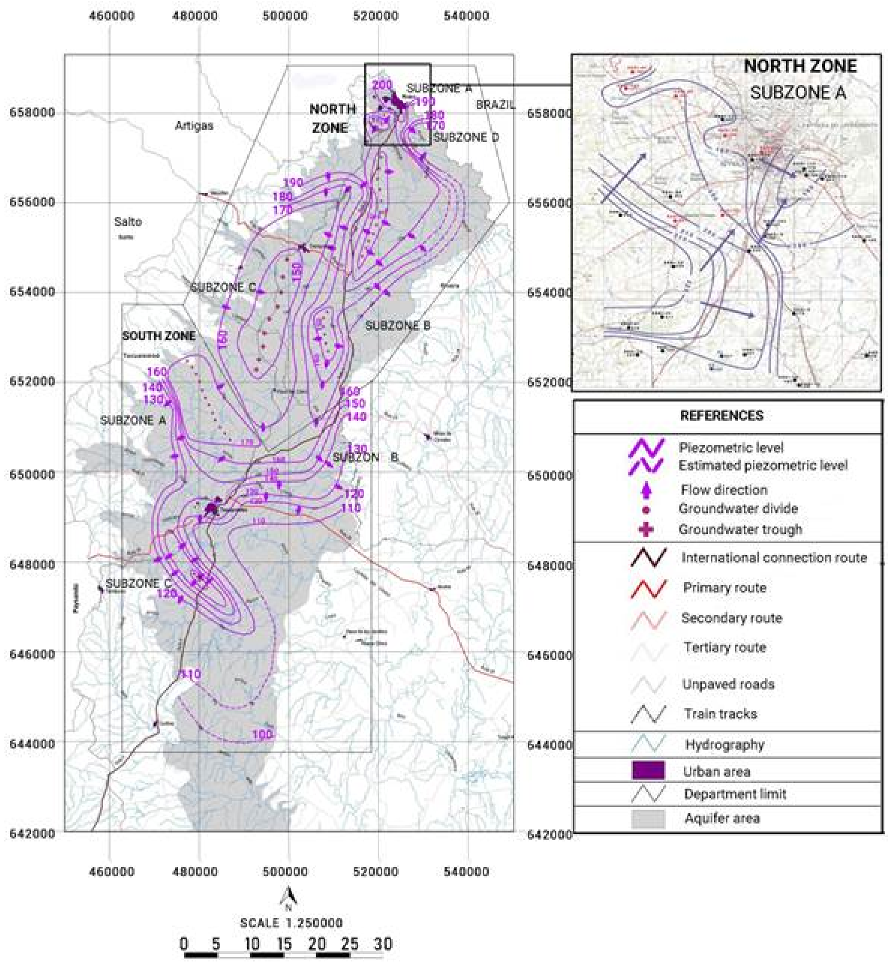


FIGURE 3
Piezometric map. “Base Line” of the outcropping Guarani Aquifer System in the departments of Rivera and Tacuarembó, Uruguay

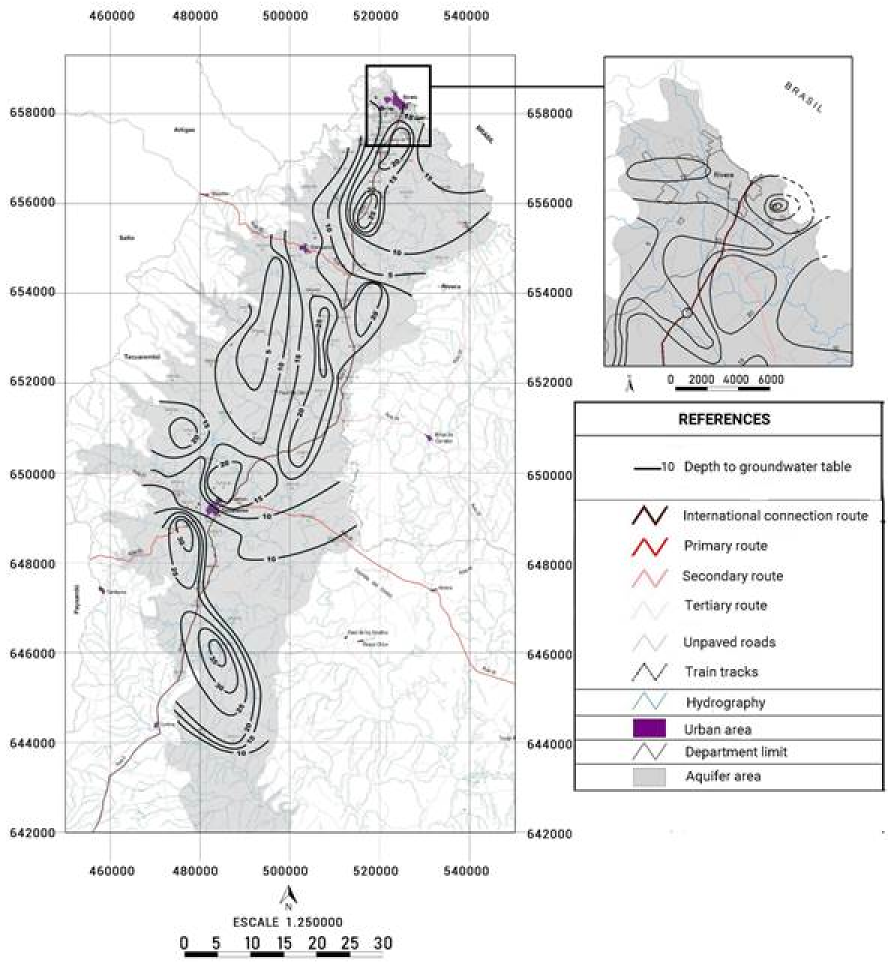


FIGURE 4
Water Table Depth "Base Line" of the outcropping Guarani Aquifer System in the departments of Rivera and Tacuarembó, Uruguay

This study also considers the risk of groundwater contamination, taking Foster & Hirata's risk concept(34), as the interaction between the natural aquifer vulnerability and the potentially polluting load applied to the soil or surface. The pollutant load refers to human activity that could generate pollution and thus alter the quality of groundwater; it is associated with the risk and does not indicate that the activity is causing damage to a given aquifer. The risk method does not refer to contamination through surface water, nor to overexploitation of aquifers.

To apply the method it is necessary to know the aquifer vulnerability, identify the potentially polluting loads and weight them according to the type of contamination, persistence, duration, disposition, etc.

In this way, the risk map will be able to contain areas that vary from very low risk to extreme risk of groundwater contamination, according to the interaction between the Vulnerability Index and the Pollutant Load. Fig. 7 reproduces the step diagram in the determination of the risk and the pollutant transport profile(35), while Fig. 8 shows the conceptual scheme of the risk of groundwater contamination(35).

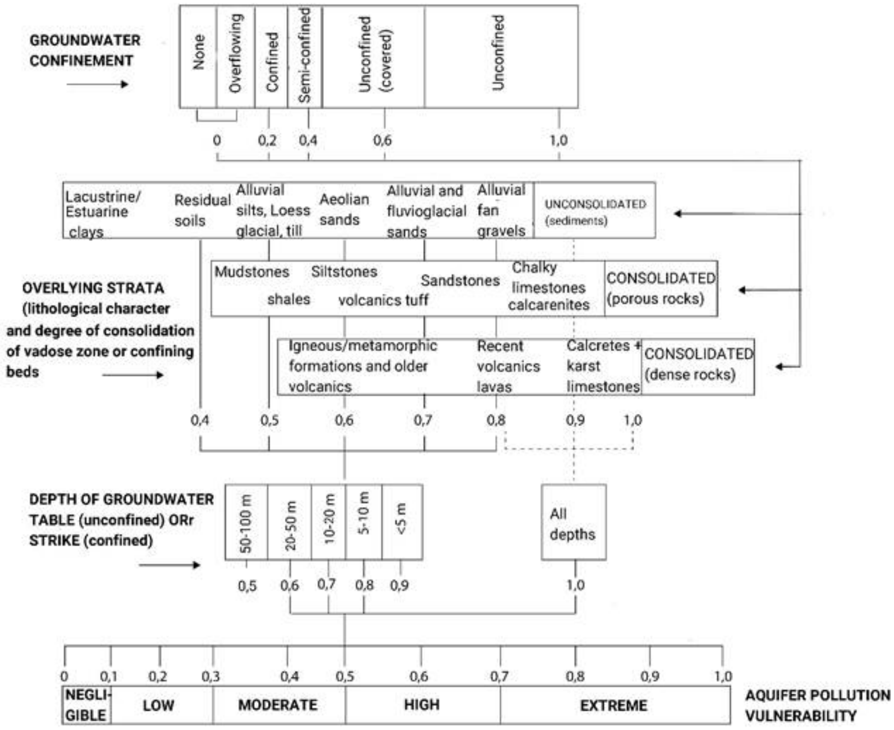
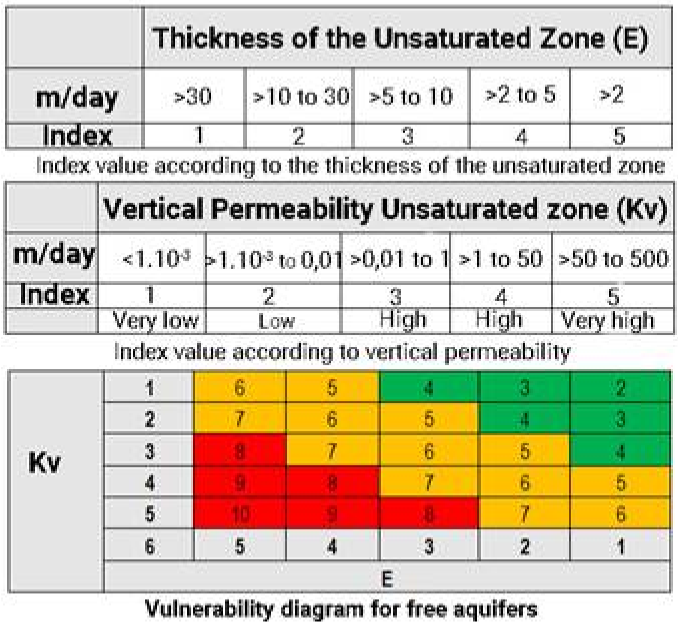


FIGURE 5
GOD Method (Modified Foster[32])



	Thickness of the Unsaturated Zone (E)				
m/day	>30	>10 to 30	>5 to 10	>2 to 5	>2
Index	1	2	3	4	5

Index value according to the thickness of the unsaturated zone

	Vertical Permeability Unsaturated zone (Kv)				
m/day	<1.10-3	>1.10-3 to 0,01	>0,01 to 1	>1 to 50	>50 to 500
Index	1	2	3	4	5
	Very low	Low	High	High	Very high

Index value according to vertical permeability

Kv	1	6	5	4	3	2
	2	7	6	5	4	3
	3	8	7	6	5	4
	4	9	8	7	6	5
	5	10	9	8	7	6
	6	5	4	3	2	1
	E					

Vulnerability diagram for free aquifers

FIGURE 6
EKV Method[33]

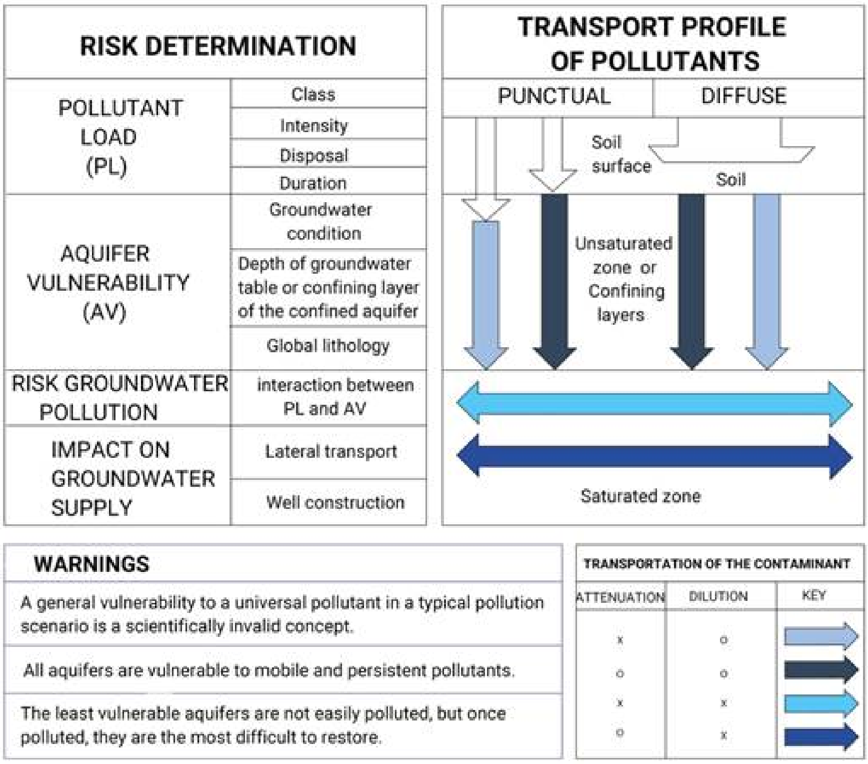


FIGURE 7
Conceptual scheme for the determination of the Risk of Groundwater Pollution[34]

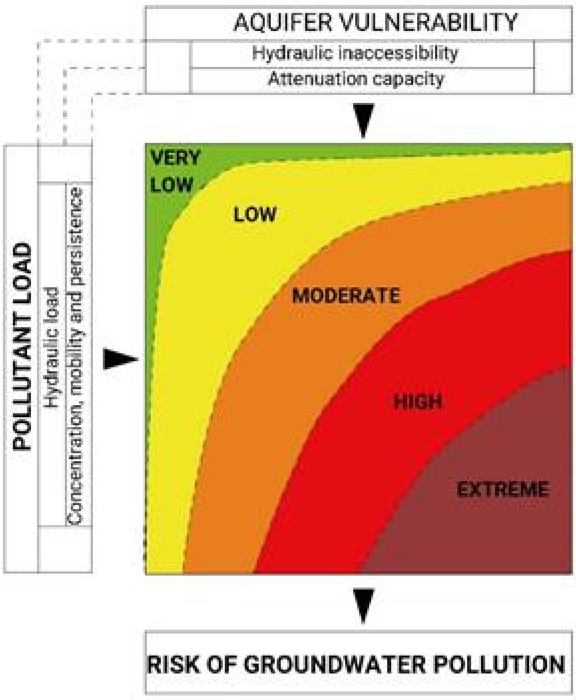


FIGURE 8
Conceptual Scheme for the Risk of Groundwater Pollution modified from[34]

3. Results and discussion

The results of the first studies in the outcropping area of the GAS are presented below and correspond to the depth of the water table, the piezometric map, the composition of the groundwater, the GOD and EKv vulnerability maps that currently constitute the baseline of the outcropping GAS in Uruguay and that will allow analyzing the aquifer behavior and establish actions that tend to its conservation, protection and sustainability. In turn, a risk analysis is presented, evaluating groundwater contamination and interaction between vulnerability and potentially polluting loads.

3.1 Water Table Depth

The depth of the water table is an extremely important variable regarding the hydrogeological behavior of a region. It is the most important variable when determining aquifer vulnerability. The greater the depth, the thicker the unsaturated area and, consequently, the greater the storage capacity. On the contrary, if it is shallow, this capacity is reduced or canceled in areas where the water table emerges. In addition, in areas with no sewage services, shallower surfaces or groundwater outcroppings cause a high risk of contamination for the population. With regard to exploitation, if the water table is deep, more powerful pumping equipment, higher energy consumption and, therefore, higher extraction costs are needed. Fig. 4 reproduces the water table map, corresponding to shallow permeable levels of the Rivera-Tacuarembó aquifer unit, and shows that values lower than 5 m are located in the center-west of the area, coinciding with the discharge area. The depth increases towards the E and NE with depths greater than 20 m, and towards the SW, where depths greater than 25 m are observed. For the city of Rivera and its surroundings, the highest values are observed in the SE of the city, with more than 30 m, where the piezometric surface tends to a depression cone. Considering the totality of the studied area, the most frequent depth of the water table is between 10 and 20 m. The greater depths coincide with the division of surface and groundwater, with correspondence between high topographic and hydraulic values with greater water table depths, and low topographic and hydraulic with lower water table depths. This relationship is typical of areas where the water balance presents notorious excess, as happens in the studied area.

3.2 Piezometry

The piezometric baseline presented is fundamental for the analysis of the hydrogeological behavior of the area. Fig. 3 reproduces the piezometric map, where a different piezometric behavior is observed in the north sector compared to the south. The limit between the two coincides approximately with the S end of the equipotential 160 m, which encloses the underground discharge area, coinciding with the Tacuarembó River. The main groundwater division in the N sector nearly coincides with the surface division, since the latter acts as a preferential recharge area.

The dominant orientation of the underground division is N-S with a deviation towards S-SW in its middle section. The dominant flow direction goes towards SE with subordinate components to the NE, where the hydraulic gradient notoriously increases, and to the W-NW towards the natural discharge zone. The natural discharge area, whose lowest equipotential is 150 m, is located to the W of the aforementioned division and is controlled in most of its extension by the Tacuarembó River (effluent). It has a subparallel orientation to the main groundwater division, with a dominant centripetal flow. The S sector has two underground divisions oriented NW-SE, with greater displacement with respect to the superficial divisions than the N sector. The dominant flow directions are towards NE and SW. In the vicinity of Tacuarembó city, a natural discharge area with NW-SE orientation begins to develop; its axis approximately coincides with the Tranqueras stream.

Locally, the following are identified:

North Sector

Subzone A: Groundwater in Rivera is of great importance since it supplies 80% of the population. This area is, therefore, the most exploited, presenting the OSE wells, in addition to the specific boreholes intended for irrigation and other uses. For this reason, the piezometry in this area tends to a depression cone, evidencing a local underground flow behavior implied by the equipotential of 190 m. The detail of the flow network in and around the city of Rivera is also depicted in Fig. 3. As mentioned, a depression cone is hinted to the SE of the city of Rivera, associated with a decrease in gradient and speed. Piezometry in this area shows a predominant flow direction to the NE, with a mean gradient between the isopieces of 190 and 185 m of $2.1x10^{3}$, and another to the SE with a mean gradient between the same isopieces of 6 $x10^{-3}$. Effective speeds are 11.9 m/year to the NE and 34 m/year towards NW - SE.

Piezometric values are higher in the SW of the city of Rivera, with a hyperbolic piezometric surface. The main flow direction is to the NE, with mean gradient between isopieces 205 and 210 m of $1x10^{-2}$ and mean speed of 56.7 m/year. Towards the S and SE, other flow directions are observed with average gradient between the isopieces 205 and 220 m of $2.3x10^{-3}$ and speed of 13 m/year to the SE, and average gradient of $1.3x10^{-2}$ and average speed of 73.8 m/year to the S, showing an increase in the hydraulic gradient to the NE and S of this sector. Between the 205 and 190 m isopieces, there is an intermediate sector to the S of the city of Rivera, where there is another increase in the hydraulic gradient that derives from a speed increase of the underground runoff. The mean gradient between the isopieces 200 and 205 m is $1x10^{2}$.

Subzone B: The piezometry in this sector shows two groundwater divisons with preferential direction N-S, with a slight deviation to the S-SO in the middle section of that located to the N. The dominant flow direction is towards the SE. The first has a parabolic piezometric surface between 210 m and 170 m to the east. The mean gradient at the isopiece 200 m is $1.7x10^{-3}$ with extremes of $1.4x10^{-3}$ and $1x10^{-2}$. The average effective speed is 9.6 m/year, with extremes of 7.9 m/year and 56.7 m/year. Towards the W-NW, heading to the natural discharge zone, the piezometric surface becomes planar, with a mean gradient at the isopiece 200 m of $7.6x10^{-3}$ and a speed of 43.1 m/year. The division located at the S is shorter. The piezometric surface becomes hyperbolic in the direction of the S flow. The mean gradient at the isopiece 180 m is $1.5x10^{-3}$ and the speed is 8.5 m/year.

Subzone C: The main area of natural discharge is located to the W of the aforementioned division, with 150 m as its lowest equipotential. This area is controlled for most of its extension by the Tacuarembó River (effluent). It has a subparallel orientation to the main groundwater division, with a dominant centripetal flow. The mean gradient is $2x10^{-3}$ at the isopiece 160 m and the speed is 11.3 m/year. The piezometric surface between 180 m and 160 m is planar.

Subzone D: The flow is oriented to the NE and SE, discharging in the Cuñapirú stream; the piezometric surface is hyperbolic between the 170 m and 190 m isopieces, and the mean gradient in the 180 m isopiece acquires a value of $1x10^{-2}$ with extremes of $9x10^{-3}$ and $1.3x10^{-2}$; the average speed is 56.7 m/year, with a maximum of 73.8 m/year and a minimum of 51.1 m/year, with a discharge flow of 0.7 hm./year, to the Cuñapirú stream.

South Sector

Subzone A: It corresponds to a recharge area, the groundwater division has NW-SE orientation. The dominant direction of flow is to NE and SW. The western sector has a piezometric surface with a hyperbolic tendency, the average gradient in the 160 m isopiece is $1.7x10^{-2}$ with extremes of $7.5x10^{-3}$ and $2.6x10^{-2}$. The average speed is 96.5 m/year, with a maximum of 147.6 m/year and a minimum of 42.5 m/year. The piezometric surface to the S manifests a dominant flow towards the S and an average gradient of 2.6 $x10^{-3}$, the speed is notoriously lower (14.7 m/year).

Subzone B: It corresponds to a dominant flow area of NW-SE and NS orientation, roughly coinciding with the Tres Cruces stream. This area presents planar piezometric surface between the 160 m and 140 m isopieces; the mean gradient in the 150 m isopieces is $4.8 x10^{-3}$ and the speed is 27.2 m/year. Following the NW-SE flow direction, the surface becomes hyperbolic between the 150 m and 130 m isopieces with an average gradient of $3x10^{-3}$ and a speed of 17 m/year.

Subzone C: Corresponds to a recharge area with the same orientation as subzone A. The dominant flow directions are towards the NE and SW; the surface is hyperbolic towards the NE. The mean gradient in the western sector is $8.8x10^{-3}$ in the 140 m isopiece and the speed is 49.9 m/year; towards the east, the average gradient is $1x10^{-2}$ in the 140 m isopiece, with a speed of 56.7 m/year and decreases to $3x10^{-3}$ in the 120 m isopiece, with a speed of 17 m/year.

3.3 Relationship between chemical composition and underground flow

The analysis of the chemical results of the groundwater (Tables 1 and 2 in complementary material) allows classifying the groundwater of the Tacuarembó Aquifer Unit as calcium bicarbonate (86%), magnesium bicarbonate (7%), calcium and sodium chloride (3.5%), and sodium bicarbonate corresponding to the underlying Buena Vista aquifer (3.5%).

Within the samples classified as calcium bicarbonates, two groups were differentiated, one with dissolved total solids (DTS) lower than 150 mg/l, with frequent conductivities between 0 and 80 mS/cm, not exceeding 150 mS/cm and pH lower than 6; and a second group with DTS greater than 150 mg/l, conductivities greater than 150 mS/cm and pH values above 6.

The results obtained with piezometry reveal that the samples of the first group, characterized by their low salinity, with similar values to rainwater, are located in recharge zones, in the N sector (subzone B) and the S sector (subzone A), generally coinciding with the highest piezometric levels. The samples of the second group, characterized by having greater salinity, are located in the S sector (subzone B), in a dominant flow area of NW–SE orientation and where the piezometric levels are lower (located mainly between the 110 and 140 m isopieces).

The samples classified as magnesium bicarbonates have pH lower than 6 and conductivities lower than 100 mS/cm; these are mainly located in the N sector (subzone B), coinciding with the 190 m isopiece, towards the W-NW in the direction of the natural discharge zone (Tacuarembó River) and where the piezometric surface becomes planar.

The samples classified as calcium chloride and sodium chloride are located below the 170 m isopiece, in discharge zones (Cuñapirú stream, Tacuarembó River). The samples that were classified as sodium bicarbonates have the highest DTS values (518 and 643 mg/l) and the highest conductivity values (600 and 750 mS/cm), and are located in the city of Tacuarembó, in the S sector (subzone B), where the Tacuarembó Formation is the shallowest (approximately 35 m). For these reasons, they are not included in the Tacuarembó Unit; it is estimated that both samples belong to the Buena Vista deep aquifer.

In Fig. 9, a local superficial and a regional flow are observed with a significant increase in the ion content in the flow direction. Based on the results and considering the entire studied area, the outcropping area of the Guarani Aquifer acts as a preferential recharge area.

In Fig. 5, a W-E cut of the study area is represented schematically, its trace is indicated in Fig. 1. It shows the local circulation flow corresponding to the Rivera-Tacuarembó aquifer unit, and a regional flow corresponding to the Buena Vista-Yaguarí aquifer unit and its underground hydrochemical evolution.

The hydrogeological basement corresponds to the Permian aquitard units, from base to ceiling: Fraile Muerto, Mangrullo and Paso Aguiar Formation.

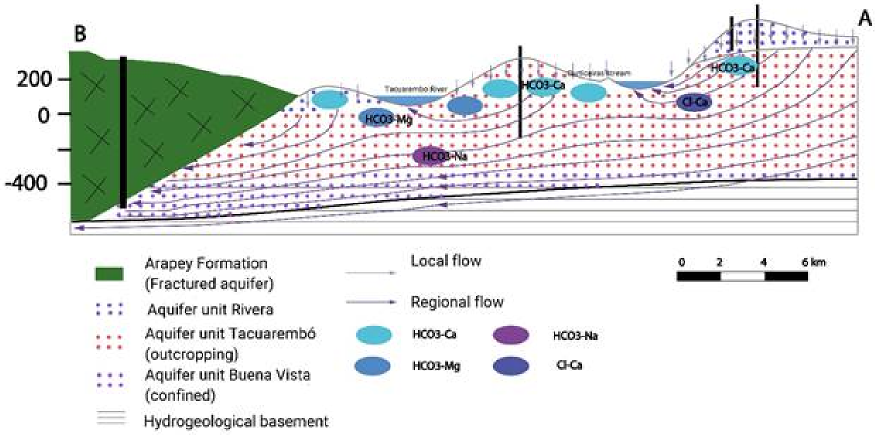


FIGURE 9
Local and regional flow model, and evolution in chemical composition

3.4 Vulnerability: GOD Method

The results of applying the GOD method for outcropping GAS are presented in Table 3. It shows the indices given to each of the variables considered and the value of the resulting index, to classify the vulnerability. It is also clear that the depth of the water table determines the classification of the system vulnerability.

TABLE 3
Vulnerability index GOD Method

Depth water table	G:	O	D	Vulnerability index	Vulnerability Classification
5-10	1,0	0,7	0,8	0,56	High
10-20	1,0	0,7	0,7	0,49	Medium
20-50	1,0	0,7	0,6	0,42	Medium

Fig. 10 presents the vulnerability map, resulting in high vulnerability for water levels below 10 m and located in the central-western sector mainly, to the S and NE, and moderate vulnerability for water levels higher than this. The vulnerability indices obtained in the studied area are similar to those obtained for the Botucatú and Piramboia Formation, in the state of San Pablo[35].

3.5 Vulnerability: EKv Method

The vulnerability obtained by this method shows slight differences from the previous method, with high vulnerability observed for water levels below 5 m and medium vulnerability for water levels above 5 m (Table 4). Like the previous method, the water table depth is the most important variable and determines the classification of vulnerability. The Vulnerability Map shows that the high vulnerability area is located mainly in the central-western sector (Fig. 11).

TABLE 4
Vulnerability index Ekv method

Depth water table	E	Kv	Vulnerability index	Vulnerability Classification
<5	4	4	8	High
5-10	3	4	7	Medium
10-30	2	4	6	Medium

Based on these maps (GOD and EKv), in high vulnerability areas, the activity should be preceded by detailed studies and, if necessary, the prohibition of polluting enterprises. In areas of moderate and low vulnerability it will depend on the type of installation and the local use of groundwater.

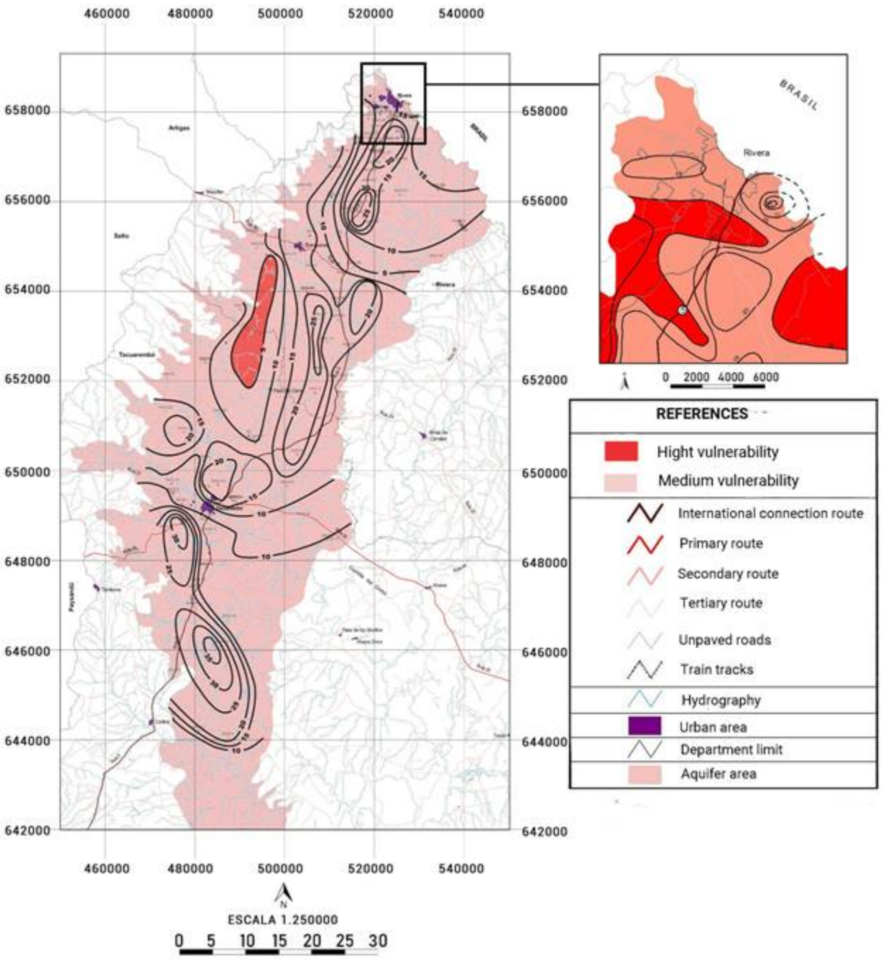


FIGURE 10
Vulnerability Map (GOD Method). "Base Line" of the outcropping Guarani Aquifer System in the departments of Rivera and Tacuarembó, Uruguay

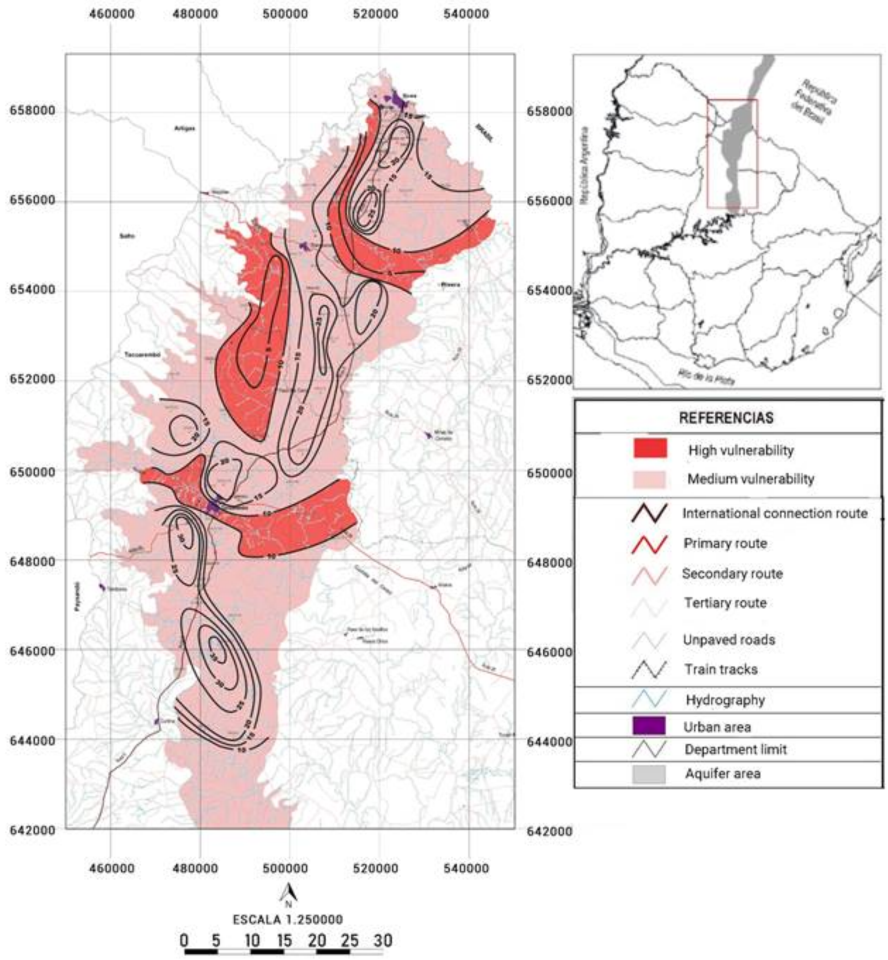


FIGURE 11
Vulnerability Map (EKv Method). “Base Line” of the outcropping Guarani Aquifer System in the departments of Rivera and Tacuarembó, Uruguay

3.6 Risk of groundwater contamination in the city of Rivera

The risk study focused specifically on the city of Rivera and surrounding areas, where a high to moderate vulnerability was mapped (Fig. 12). In terms of the pollutant load, the low percentage of coverage of the sanitation system and the irregular human settlements generate significant pollutant loads. To determine the risk, the main activities that could generate groundwater contamination were identified, separating them into punctual and diffuse. Table 5 indicates the risk of groundwater contamination from the interaction between the potentially polluting load surveyed and vulnerability. The location of potentially polluting loads and vulnerability is shown in Fig. 12.

TABLE 5
Risk of groundwater contamination in the outcropping GAS

RISK OF GROUNDWATER POLLUTION		VULNERABILITY	
		Moderate	High
POTENTIALLY POLLUTING LOAD ACTIVITIES	Industrial and Mining Activity: (Reduced to Moderate)	Low to Moderate	Moderate to High
	Solid household waste (Elevated)	High	High
	Irregular settlements (Elevated)	High	High
	Cemetery (Moderate)	Moderate	High
	Gas stations (Elevated)	High	High
	Sites with Sanitation (Elevated)	High	High
	Agrochemicals use (Moderate to Elevated)	High	High

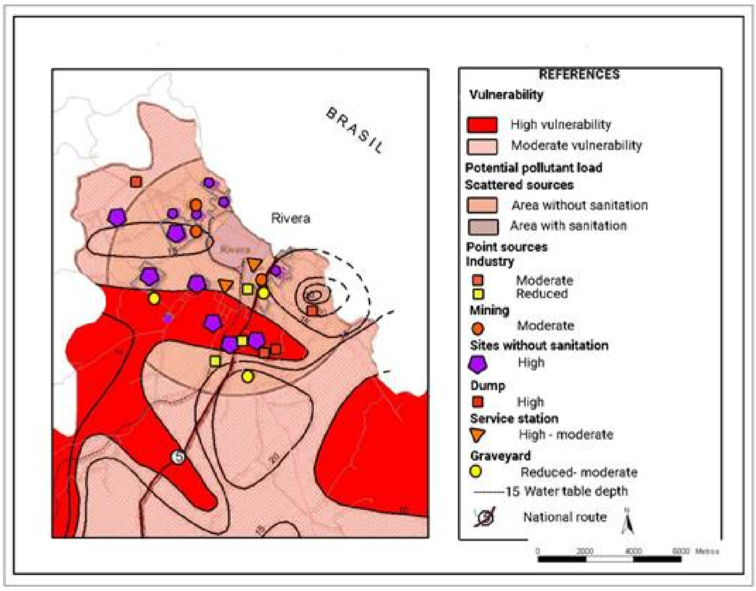


FIGURE 12
Vulnerability Map and potentially polluting loads in the city of Rivera and surroundings Department of Rivera Uruguay

4. Conclusions

The outcropping Guarani Aquifer in the departments of Rivera and Tacuarembó, Uruguay, consists of two sections or units. The upper, of greater productivity, restricted to the N and contained in the Rivera Formation; and the lower one, covering the entire studied area and named the Tacuarembó Unit. The vertical communication between both units results in similar hydraulic potentials and chemical compositions. The recharge process of the outcropping Guarani Aquifer occurs directly by infiltration of meteoric water. The Buena Vista-Yaguarí Unit is underlying this and is part of the GAS, but in confinement conditions.

The piezometry of the Tacuarembó Unit shows two different sectors, the N and the S. In the northern sector, the main groundwater division nearly coincides with the surface division, being the dominant orientation N-S. The main flow direction is towards the SE with subordinate components towards the NE, where the hydraulic gradient is notoriously increased, and towards the W-NW in the direction of the natural discharge zone. The natural discharge area is located to the W and is controlled in most of its extension by the Tacuarembó River (effluent). The S sector has two underground divisions oriented NW-SE, with greater displacement with respect to the superficial divisions than the N sector. The dominant flow directions are towards NE and SW.

Total groundwater extraction in the region amounts to 10.5 hm./a. Human supply in the urban area requires the largest extraction volume, 67% of the total. In rural areas, irrigation, domestic and livestock use stand out with a consumption of 25%, and to a lesser extent, an 8% is used to cover industrial demand.

Regarding the chemical composition, there is a marked similarity between the Rivera and Tacuarembó units, as a consequence of the hydraulic communication. In both, calcium bicarbonate waters (80%) predominate over magnesium bicarbonates (20%), with saline contents of 60 mg/l and 152 mg/l. Within the bicarbonate calcium waters of the Tacuarembó Unit, two groups are differentiated, one with DTS content below 150 mg/l and pH below 6, and a second group with DTS above 150 mg/l and pH above 6. This difference occurred since the samples of the first group are located in recharge zones, N sector (subzone B) and S sector (subzone A), generally coinciding with the highest piezometric levels, and the samples of the second group are located in the S sector (subzone B), where a dominant flow area of NW-SE orientation is highlighted and the piezometric levels are lower (located mainly between the 110 and 140 m isopieces).

In 26 samples from both units, the pH is lower than 6, with the mean value for the Rivera Unit being 5.7.

Regarding vulnerability, and applying the GOD method, a high vulnerability is obtained for water levels lower than 10 m, located in the central-west sector mainly, to the S and NE, and a medium or moderate vulnerability for levels higher than this. The use of the EKv method resulted in high vulnerability for water levels lower than 5 m deep and a medium vulnerability for higher levels. Both methods produce similar vulnerability maps, mapping high vulnerability in the center-west of the area. However, the EKv method classifies as high vulnerability, areas where water levels are lower than 5m, thus increasing high vulnerability areas. It is concluded that both methods were correctly adjusted to the study area, producing reliable maps.

The water table depth is the most important variable to determine the vulnerability classification (Tables 3 and 4, and Figs. 10 and 11). As indicated by Foster and others[(36)], it is misguided to believe that using more complex methods that consider a greater number of variables produces more reliable maps and closer to the system reality. In this specific case of the outcropping Guarani Aquifer, the use of other complex methods would not improve the vulnerability mapping, since the area does not present important changes in the topography, in the recharge of the system or the types of soil, being the depth of the water table and the vertical permeability the most important variables to study in detail and locally, according to the use of the soil and the potentially polluting load.

Regarding the risk of groundwater contamination, vulnerability and potentially polluting load were considered, resulting in high risk due to lack of sanitation, solid household waste, irregular settlements and gas stations. Industrial activity, cemeteries and mining represent moderate risk in most cases.

It is essential for these areas, where the risk of contamination is high, to have resources for confirmatory and detailed research that tends to the preservation of the groundwater resource and allows better decision making, in terms of territorial planning, avoiding its deterioration.

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Table 1. Wells registered in the outcropping GAS area in the departments of Rivera and Tacuarembó, Uruguay

TABLE 1

Wells registered in the outcropping GAS area in the departments of Rivera and Tacuarembó, Uruguay

ID	Coord. X	Coord. Y	Coord. Z	Well Depth.	GT (m)	SP acot.(m)	ID	Coord. X	Coord. Y	Coord. Z	Well Depth.	GT (m)	SP (m)
SAGr-1	512.80	6510.65	140	82.0	8.0	132.0	SAGt-1	480.85	6441.95	110	7.5	7.0	103.0
SAGr-2	512.85	6516.65	160	11.4	2.5	157.5	SAGt-2	487.43	6440.42	140	54.0	19.7	120.3
SAGr-3	506.85	6517.40	195	37.0	22.3	172.7	SAGt-3	488.96	6493.18	170	36.0	18.5	151.5
SAGr-4	526.05	6574.90	200	55.0	23.7	176.3	SAGt-4	493.50	6506.00	180	17.0	11.2	160.8
SAGr-5	518.80	6581.25	215	15.0	6.2	208.8	SAGt-5	494.10	6506.80	170	38.0	9.3	160.8
SAGr-6	529.35	6573.05	179	64.0	0	179.0	SAGt-6	482.15	6495.67	164	18.0	9.8	154.2
SAGr-7	506.06	6544.85	170	18.0	15.4	154.6	SAGt-7	477.60	6508.60	200	65.4	25.3	174.8
SAGr-8	524.73	6578.60	208	61.0	19.0	189.0	SAGt-8	477.15	6492.60	150	34.0	10.0	140.0
SAGr-9	524.11	6577.88	230	53.8	25.2	204.9	SAGt-9	475.15	6495.00	160	42.0	12.7	147.3
SAGr-10	523.64	6579.40	220	23.0	9.5	210.6	SAGt-10	474.85	6497.10	140	40.0	8.3	131.8
SAGr-11	525.60	6578.20	210	60.5	11.5	198.5	SAGt-11	475.05	6494.39	161	27.0	5.5	155.5
SAGr-12	526.13	6571.79	213	56.0	13.5	199.5	SAGt-12	485.90	6460.95	160	57.0	37.0	123
SAGr-13	523.88	6573.20	233	50.0	23.2	209.8	SAGt-13	479.08	6469.09	140	45.0	25.0	115.0
SAGr-14	524.00	6573.27	233	66.0	14.1	218.9	SAGt-14	482.40	6488.35	140	32.0	16.5	123.5
SAGr-15	526.00	6571.97	210	70.0	13.2	196.8	SAGt-15	483.25	6486.10	155	46.0	12.2	142.9
SAGr-16	520.47	6572.42	211	28.0	14.8	196.3	SAGt-16	482.40	6478.35	140	42.0	13.6	126.4
SAGr-17	520.26	6570.32	230	84.0	42.0	188.0	SAGt-17	482.70	6478.30	140	46.5	13.8	126.2
SAGr-18	517.79	6561.80	220	74.0	37.9	182.1	SAGt-18	480.60	6474.80	190	47.0	25.7	164.4
SAGr-19	519.65	6573.26	214	86.0	12.9	201.2	SAGt-19	473.50	6486.65	170	42.0	20.0	150.0
SAGr-20	511.10	6566.92	210	30.0	15.9	194.1	SAGt-20	465.96	6481.57	179	20.0	5.8	173.2
SAGr-21	510.78	6560.65	165	30.0	5.1	159.9	SAGt-21	477.8	6488.22	150	76.0	31.0	119.0
SAGr-22	513.93	6557.75	200	40.0	21.4	178.6	SAGt-22	488.50	6493.35	175	44.0	14.6	160.4
SAGr-23	516.00	6556.91	220	42.0	30.6	189.4	SAGt-23	510.45	6484.0	140		15.5	124.5
SAGr-24	526.53	6543.62	160	34.0	4.2	155.8	SAGt-24	504.05	6484.0	120	34.5	16.5	123.5
SAGr-25	520.64	6561.50	220	18.0	13.1	206.9	SAGt-25	473.40	6513.20	140	34.5	16.5	123.5
SAGr-26	533.90	6562.90	215	50.0	15.0	200.0	SAGt-26	473.75	6520.70	190	24.2	12.9	177.1
SAGr-27	534.30	6562.60	210	40.0	12.9	197.1	SAGt-27	482.55	6523.90	220	29.3	13.4	206.6
SAGr-28	538.62	6554.84	215		10.4	204.6	SAGt-28	482.30	6524.20	180	47.5	12.3	167.7
SAGr-29	533.60	6547.12	195	50.0	13.2	181.8	SAGt-29	492.75	6530.70	140	42.0	1.1	139.0
SAGr-30	534.25	6540.61	185		22.7	162.3	SAGt-30	485.20	6496.80	185		37.5	147.5
SAGr-31	509.37	6528.60	215	20.0	15.4	199.6	SAGt-31	483.66	6490.29	140	54.4	8.0	132.0
SAGr-32	490.20	6536.00	170	45.0	13.0	157.0	SAGt-32	502.82	6503.62	190	30.0	22.7	167.3
SAGr-33	511.75	6533.70	195	37.0	18.5	176.5	SAGt-33	487.55	6466.74	135	35.0	17.0	118.0
SAGr-34	525.24	6581.47	225	44.0	13.0	212.0	SAGt-34	479.90	6473.3	130	46.0	21.1	108.9
SAGr-35	521.63	6580.27	215	36.0	11.0	204.0	SAGt-37	509.61	6484.64	144	57.0	7.0	137.0
SAGr-36	521.54	6580.05	225	60.0	15.9	209.1	SAGt-38	485.51	6512.58	142	30.0	11.4	130.6
SAGr-38	524.40	6582.35	205	36.0	11.0	194.0	SAGt-39	513.04	6543.41	204	10.0	2.0	202.0
SAGr-39	520.89	6577.23	240	42.5	10.6	229.5	SAGt-40	483.17	6492.45	140	80	28	112.0
SAGr-40	520.59	6575.93	225	17.0	7.6	217.4	SAGt-42	500.50	6496.0	150	46.0	14.0	136.0
SAGr-41	519.09	6574.38	235	72.0	19.1	215.9	SAGt-43	481.90	6502.30	160	41.0	8.8	151.2
SAGr-42	526.76	6580.93	205	49.0	23.0	182.0	SAGt-44	512.86	6570.56	233	21.0	18.0	215.0
SAGr-43	528.80	6578.28	205	60.0	15.7	189.3	SAGt-45	489.20	6486.68	130	42.0	5.0	125.0
SAGr-44	528.71	6578.37	199	41.0	14.0	185.0	SAGt-46	489.20	6486.68	130	42.0	5.0	125.0
SAGr-50	515.39	6545.45	215		5.5	209.6	SAGr-76	521.18	6584.74	210.0	120.00	15.6	194.4
SAGr-51	517.65	6541.35	205	45.0	23.2	181.8	SAGr-78	525.20	6581.80	240.0	128.00	64.0	176.0
SAGr-52	496.92	6547.24	175		4.0	171.0	SAGr-79	523.22	6585.00	210.0	130.30	30.0	180.0
SAGr-53	493.83	6549.73	165	9.0	8.2	156.9	SAGr-81	518.40	6586.00	215.2	133.00	11.6	203.6
SAGr-54	492.58	6552.68	165	42.0	5.3	159.7	SAGr-82	524.04	6581.30	190.0	134.00	3.5	186.5
SAGr-55	520.28	6570.57	235	48.0	17.4	217.6	SAGr-84	524.08	6578.00	230.0	50.00	22.7	207.3
SAGr-56	520.25	6570.55	235		14.7	220.4	SAGr-85	523.38	6583.00	210.0	147.00	12.3	197.7
SAGr-57	522.12	6570.02	225	96.0	29.0	196.0	SAGr-86	524.06	6579.00	230.0	50.60	19.0	211.0
SAGr-58	518.82	6566.19	235		7.6	227.4	SAGr-87	518.58	6586.00	210.0	81.00	9.0	201.0
SAGr-59	519.38	6554.64	225	30.0	11.2	213.8	SAGr-88	518.96	6585.53	213.0	65.00	4.6	208.6
SAGr-60	511.79	6537.63	195	14.5	7.3	187.7	SAGr-89	519.26	6585.34	213.0	62.00	5.6	207.4
SAGr-61	504.98	6539.87	185	48.0	19.6	165.5	SAGr-90	526.38	6581.00	196.0	68.00	21.3	174.7
SAGr-62	505.09	6539.81	185	15.0	5.3	179.7	SAGr-91	523.24	6580.00	220.0	78.00	10.0	210.0
SAGr-63	525.72	6561.61	215		0	215.0	SAGr-92	521.28	6579.00	200.0	56.30	19.8	180.2
SAGr-64	525.74	6568.69	215	41.0	19.0	196.0	SAGr-93	526.94	6581.00	210.0	70.50	11.6	198.4
SAGr-65	518.65	6563.94	225	30.0	11.0	214.0	SAGr-94	519.26	6586.00	210.0	55.00	13.0	197.0
SAGr-66	514.24	6527.31	185	50.0	18.7	166.3	SAGr-96	523.12	6579.00	210.0	87.00	7.0	203.0
SAGr-67	507.75	6534.02	235	60.5	37.0	198.0	SAGr-98	523.44	6585.20	260.0	163.50	86.7	173.3
SAGr-68	519.80	6567.90	235	40.0	20.2	214.9	SAGr-100	524.90	6579.35	195.0	53.00	7.4	187.6
SAGr-69	520.70	6580.30	210	15.5	7.7	202.3	SAGr-103	525.48	6581.54	220.0	71.00	20.3	199.7
SAGr-70	513.70	6520.41	198	40.0	20.0	178.0	SAGr-104	524.04	6585.34	210.0	68.00	26.3	183.7
SAGr-72	507.62	6522.06	188	51.0	25.0	163.0	SAGr-105	476.72	6492.66	160.0	62.00	5.7	154.3
SAGr-107	523.18	6584.30	202.0	93.00	10.0	192.0	SAGr-106	481.88	6474.19	200.0	128.00	45.2	154.8

(ID: Identification, Coord: Coordinates, GT: Groundwater table, SP: Piezometric Surface.)

Table 2. Results of chemical composition of groundwater, GAS outcropping area in the departments of Rivera and Tacuarembó, Uruguay

TABLE 2
Results of chemical composition of groundwater, GAS outcropping area in the departments of Rivera and Tacuarembó, Uruguay

ID	pH	Cond. (µS/cm)	Temp. (ºC)	HCO3 (mg/l)	Ca (mg/Ca)	Mg (mg/l)	K (mg/l)	Na (mg/l)	Fe (mg/l)	NO3 (mg/l NO3)	Cl (mg/l Cl)	SO4 (mg/l SO4)	STD (mg/l)	Hardness (mg/l)
SAGr-6	6.24	130	19.8	68.75	16.58	3.24	3.50	3.70	<0.1	1.70	0.72	0.40	99.99	54.75
SAGr-8	5.90	149	20.0	58.01	38.86	0.00	1.60	3.90	<0.1	22.10	7.89	2.00	137.36	97.05
SAGr-13	5.40	76	19.0	8.19	7.37	2.25	2.00	0.80	<0.1	11.10	2.15	0.00	34.86	27.67
SAGr-15	5.35	75	20.0	16.38	6.63	1.45	1.50	0.70	<0.1	0.81	11.00	0.20	39.86	22.53
SAGr-16	5.18	72	19.0	10.74	8.84	1.90	1.60	0.80	<0.1	10.50	2.63	2.10	42.21	29.90
SAGr-17	5.33	59	19.0	14.02	6.44	2.12	1.80	0.60	<0.1	5.31	0.00	3.90	39.08	24.81
SAGr-18	6.08	103	20.0	41.33	10.31	5.13	2.50	1.10	<0.1	2.57	2.15	15.60	97.32	46.87
SAGr-19	5.53	36	20.0	15.96	3.13	3.57	1.90	0.50	<0.1	1.52	0.00	12.70	52.96	22.52
SAGr-20	5.57	54	19.0	13.60	5.34	4.35	0.30	0.10	<0.1	3.10	0.00	11.80	51.39	31.25
SAGr-21	5.26	185	19.0	17.20	8.28	5.25	2.10	16.30	<0.1	10.82	17.93	17.20	113.26	42.30
SAGr-22	5.50	51	20.0	13.88	6.63	2.23	1.80	1.70	<0.1	4.34	5.50	11.80	60.64	25.74
SAGr-23	5.90	63	20.0	11.51	3.68	4.13	1.15	0.20	<0.1	4.25	3.11	0.30	29.68	26.20
SAGr-26	5.68	77	20.0	25.40	3.68	4.80	0.90	4.10	<0.1	3.03	1.43	14.30	72.91	28.96
SAGr-28	5.96	47	19.0	15.29	5.16	2.12	1.30	2.10	<0.1	2.20	0.60	0.20	30.17	21.62
SAGr-29	5.21	379	20.0	25.81	27.44	9.47	5.70	10.90	<0.1	20.06	32.76	26.70	186.58	107.53
SAGr-39	6.93	188	20.0	111.56	36.11	1.34	0.10	5.20	<0.1	1.85	1.67	0.20	159.28	95.70
SAGr-44	5.70	65	19.0	15.68	3.50	4.35	1.80	0.50	<0.1	3.72	3.11	0.30	34.24	26.65
SAGr-51	5.74	65	20.0	22.48	7.37	2.90	1.90	2.10	<0.1	1.66	0.84	2.70	45.69	30.35
SAGr-52	7.29	195	20.0	73.99	27.22	8.75	1.70	6.90	<0.1	4.01	13.75	13.80	164.91	104.01
SAGr-54	6.89	217	19.0	138.96	38.02	8.87	0.70	5.20	<0.1	0.00	1.08	3.00	199.83	131.48
SAGr-64	5.70	35	18.0	11.52	4.60	2.57	1.00	0.10	<0.1	2.40	0.48	1.60	26.87	22.07
SAGr-66	5.56	85	20.0	18.56	8.48	5.13	2.60	2.80	<0.1	6.20	6.46	3.30	57.83	42.30
SAGt-2	7.18	630	19.0	284.91	104.19	10.79	1.70	16.40	<0.1	31.25	23.50	3.80	481.39	304.64
SAGt-3	6.37	195	18.0	102.94	32.54	6.98	2.10	3.30	<0.1	2.79	3.83	4.30	164.09	110.01
SAGt-5	6.31	101	21.0	33.61	11.21	9.00	2.50	0.90	<0.1	6.10	5.70	6.90	83.82	65.06
SAGt-13	5.98	228	20.5	125.39	32.02	3.40	0.40	5.90	<0.1	2.20	4.54	15.60	206.05	93.97
SAGt-21	7.58	335	18.0	218.60	39.42	17.51	2.60	20.70	0.28	0.00	3.83	3.30	306.24	170.55
SAGt-23	7.48	488	18.0	302.35	63.21	10.11	4.60	39.00	<0.1	7.97	8.13	0.40	437.20	199.49
SAGt-24	6.95	439	19.0	265.50	55.43	18.12	3.00	22.00	<0.1	6.36	8.25	6.20	392.10	213.05
SAGt-25	6.75	186	19.0	74.57	27.22	9.00	0.90	5.70	<0.1	7.20	9.40	6.80	148.59	105.04
SAGt-29	7.98	360	19.0	239.68	42.64	16.52	2.30	30.20	<0.1	1.69	4.66	3.20	345.10	174.52
SAGt-31	8.35	600	20.0	314.05	21.61	11.43	1.70	112.20	<0.1	3.88	21.76	15.20	518.05	101.04
SAGt-33	7.83	262	19.0	260.19	50.86	14.09	2.20	2.51	<0.1	6.93	13.30	6.70	364.45	185.04
SAGt-34	5.02	102	20.0	43.77	16.01	5.59	2.20	6.10	<0.1	5.60	4.90	5.70	96.57	63.00
SAGt-38	7.59	363	18.0	258.13	47.23	26.38	0.40	6.90	<0.1	0.53	2.15	0.30	343.29	226.59
SAGt-44	7.7	50	19.0	29.50	11.60	4.77	0.90	0.00	<0.1	1.15	0.00	6.90	62.77	48.61
SAGt-45	_	_	_	477.00	81.00	13.00	1.70	45.00	<0.1	1.80	8.00	2.00	_	256.65
SAGt-46	_	_	_	354.00	49.00	11.00	2.40	39.00	<0.1	1.80	11.00	5.00	_	168.50
SAGt-47	_	_	_	54.00	3.90	6.20	1.60	8.20	<0.1	5.40	3.00	8.00	_	35.50
SAGt-67	_	80		18.85	8.60	5.68	1.60	2.40	<0.1	7.57	4.06	3.20	56.19	44.87
SAGr-11	5.60	39	20.0	11.39	5.90	2.68	1.20	0.20	<0.1	2.50	1.32	14.10	54.39	25.77
SAGr-42	5.30	76	19.0	16.93	8.29	2.79	2.80	0.80	<0.1	4.11	5.74	2.90	48.25	32.19
SAGr-46	5.05	148	19.0	42.19	9.95	7.14	5.70	1.50	<0.1	3.05	11.96	12.40	107.34	54.25
SAGr-60	5.50	35	20.0	16.10	4.79	3.35	1.40	0.80	<0.1	1.06	0.00	2.40	33.34	25.76
SAGr-65	5.60	26	20.0	12.93	2.95	4.91	1.90	0.30	<0.1	1.30	0.00	4.80	34.89	27.59
SAGr-68	5.54	39	19.0	13.46	5.89	1.56	1.90	0.70	<0.1	3.45	0.00	0.90	29.81	21.13
SAGr-71	*	41	19.0	24.36	4.49	5.57	1.50	0.30	<0.1	1.15	0.48	12.90	64.70	34.15
SAGt-27	6.84	88	18.7	49.14	9.20	11.67	1.50	1.60	<0.1	0.90	1.91	15.20	107.32	71.03
SAGr-69	6.43	222	19.0	120.30	21.18	16.25	2.90	19.50	<0.1	7.90	11.30	13.90	228.13	119.81
SAGr-70	5.53	161	20.0	9.14	14.36	6.02	2.60	3.00	<0.1	18.93	19.25	1.60	77.47	60.65
SAGr-30	6.58	236	22.0	108.46	26.90	1.12	2.30	20.40	<0.1	3.32	8.85	5.80	183.93	71.79

(ID: Identification, Coord: Coordinates)

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