ENVIRONMENTAL CHARACTERIZATION OF THE GUARANI AQUIFER SYSTEM (SAG) IN MATO GROSSO DO SUL (MS) AND GROUNDWATER QUALITY

CARACTERIZAÇÃO AMBIENTAL DO SISTEMA AQUÍFERO GUARANI (SAG) NO MATO GROSSO DO SUL (MS) E A QUALIDADE DAS ÁGUAS SUBTERRÂNEAS

CARACTERIZACIÓN AMBIENTAL DEL SISTEMA ACUÍFERO GUARANÍ (SAG) EN MATO GROSSO DO SUL (MS) Y CALIDAD DE LAS AGUAS SUBTERRÁNEAS

10.56238/edimpacto2025.058-002

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ABSTRACT

The study analyzed environmental changes and groundwater quality in the Guarani Aquifer System (GAS) in Mato Grosso do Sul (MS), Brazil, between 2002 and 2022, using MapBiomas data and IMASUL monitoring. Results showed a decline in natural formations, including forests (-1.3%) and savannas (-2.4%), while agricultural crops (soybeans: +2.22%) and planted forests (+0.9%) expanded. Pasturelands remained dominant (52.1% in 2022) but decreased slightly (-2.7%), and urbanization grew modestly (+0.3%), raising concerns over soil sealing in recharge zones . Water quality analysis (2018–2022) identified nitrate contamination exceeding CONAMA 396/2008 limits (10 mg/L) in wells like ALC-005 (14.8 mg/L), linked to agricultural fertilizers. Microbiological pollution (total coliforms and E. coli) was detected in wells such as DOU-036, indicating sewage or animal waste infiltration. Physical-chemical parameters (pH: 5.0–8.3; conductivity: 17.3–285 µS/cm) generally met standards, while turbidity (<0.5–3.3 NTU) remained below the WHO limit (5 NTU) . Key risks include intensive agriculture (agrochemicals and irrigation), deforestation (reducing infiltration and increasing erosion), and inadequate sanitation (worsening contamination). Sustainable management requires integrated policies: recharge area zoning, well monitoring, agrochemical regulation, and investments in sanitation and sustainable farming . The aquifer's preservation depends on collaboration among public and private sectors and local communities, aligned with legal frameworks like CONAMA 396/2008 and PERH-MS. Overexploitation and pollution demand urgent action to prevent water crises, especially under climate change and growing demand .

Keywords: Guarani Aquifer System. Water Quality. Land Use. Water Management. Mato Grosso do Sul.

RESUMO

O estudo analisou a caracterização ambiental do Sistema Aquífero Guarani (SAG) no Mato Grosso do Sul (MS) e a qualidade das águas subterrâneas entre 2002 e 2022, utilizando dados do MapBiomas e monitoramento do IMASUL. Os resultados revelaram redução nas formações naturais, como florestas (-1,3%) e savanas (-2,4%), enquanto culturas agrícolas (soja: +2,22%) e florestas plantadas (+0,9%) expandiram-se. As pastagens, embora dominantes (52,1% em 2022), apresentaram leve declínio (-2,7%), e a urbanização cresceu modestamente (+0,3%), com preocupação quanto à impermeabilização do solo em zonas de recarga . Na qualidade da água (2018–2022), destacaram-se casos de contaminação por nitratos acima do limite da CONAMA 396/2008 (10 mg/L), como no poço ALC-005 (14,8 mg/L), associados a fertilizantes agrícolas. Também foi detectada presença de coliformes totais e *E. coli* em poços como DOU-036, indicando infiltração de esgoto ou dejetos animais. Parâmetros físico-químicos, como pH (5,0–8,3) e condutividade elétrica (17,3–285 µS/cm), mantiveram-se geralmente dentro dos padrões, mas a turbidez (<0,5–3,3 NTU) permaneceu abaixo do limite da OMS (5 NTU). Os principais riscos identificados incluem a agricultura intensiva (com uso de agroquímicos e irrigação), o desmatamento (que reduz a infiltração e aumenta a erosão) e o saneamento inadequado (que agrava a contaminação). Para garantir a sustentabilidade do SAG/MS, são necessárias políticas de gestão integrada, como: zoneamento de áreas de recarga, monitoramento contínuo de poços, fiscalização de agroquímicos e investimentos em saneamento básico e práticas agrícolas sustentáveis . A preservação do aquífero depende da cooperação entre setores públicos, privados e comunidades locais, alinhada a marcos legais como a CONAMA 396/2008 e o PERH-MS. A superexploração e a contaminação exigem ações urgentes para evitar crises hídricas, especialmente em cenários de mudanças climáticas e aumento da demanda .

Palavras-chave: Sistema Aquífero Guarani. Qualidade da Água. Uso da Terra. Gestão Hídrica. Mato Grosso do Sul.

RESUMEN

El estudio analizó la caracterización ambiental del Sistema Acuífero Guaraní (SAG) en Mato Grosso do Sul (MS) y la calidad de las aguas subterráneas entre 2002 y 2022, utilizando datos del monitoreo MapBiomas e IMASUL. Los resultados revelaron una reducción en las formaciones naturales, como bosques (-1,3%) y sabanas (-2,4%), mientras que los cultivos agrícolas (soja: +2,22%) y los bosques plantados (+0,9%) se expandieron. Los pastizales, aunque dominantes (52,1% en 2022), mostraron un ligero descenso (-2,7%), y la urbanización creció modestamente (+0,3%), con preocupaciones respecto a la impermeabilidad del suelo en las zonas de recarga. En la calidad del agua (2018-2022) se destacaron casos de contaminación por nitratos por encima del límite CONAMA 396/2008 (10 mg/L), como en el pozo ALC-005 (14,8 mg/L), asociado a fertilizantes agrícolas. La presencia de coliformes totales y *E. También se detectó. coli* en pozos como DOU-036, lo que indica infiltración de aguas residuales o desechos animales. Los parámetros fisicoquímicos como el pH (5,0–8,3) y la conductividad eléctrica (17,3–285 µS/cm) generalmente se mantuvieron dentro de los estándares, pero la turbidez (<0,5–3,3 NTU) se mantuvo por debajo del límite de la OMS (5 NTU). Los principales riesgos identificados incluyen la agricultura intensiva (con uso de agroquímicos y riego), la deforestación (que reduce la infiltración y aumenta la erosión) y el saneamiento inadecuado (que agrava la contaminación). Para asegurar la sostenibilidad del SAG/MS son necesarias políticas de gestión integrada, como: zonificación de áreas de recarga, monitoreo continuo de pozos, inspección de agroquímicos e inversiones en saneamiento básico y prácticas agrícolas sostenibles. La preservación del acuífero depende de la cooperación entre los sectores público y privado y las comunidades locales, de acuerdo con marcos legales como CONAMA 396/2008 y PERH-MS. La sobreexplotación y la contaminación exigen acciones urgentes para evitar crisis hídricas, especialmente en escenarios de cambio climático y aumento de la demanda.

Palabras clave: Sistema Acuífero Guaraní. Calidad del Agua. Uso del Suelo. Gestión del Agua. Mato Grosso do Sul.

1 INTRODUCTION

Water is essential for the survival of all life on the planet. Although two-thirds of the earth's surface is covered by water, only a small fraction is drinkable. Of the water resources available for consumption, 96% comes from underground sources, which are essential for supplying large populations around the world.

In Brazil, according to the IBGE (2000), about 55% of the municipalities are supplied by groundwater, with cities such as Ribeirão Preto (SP), Maceió (AL), Mossoró (RN) and Manaus (AM) using this resource exclusively. In addition to serving the population, groundwater is essential for industry, agriculture, leisure and other activities.

However, due to the growing demand, these waters are under great pressure. Overexploitation, which occurs when extraction exceeds natural replacement, can result in impacts such as a decrease in the volume of water in rivers, the drying up of springs, and the depletion of reservoirs. In addition, water pollution, from human activities such as cesspools, domestic and industrial sewage, leaks from gas stations, dumps and the use of pesticides in agriculture, aggravates the situation.

Freshwater scarcity is a growing risk, driven by these factors and a lack of awareness. The preservation of groundwater reserves is crucial for future generations, requiring special care to ensure its sustainable use.

Groundwater is the water present underground, seeping by gravity through soil, rocks, and fissures. This process occurs in two zones: the unsaturated zone, where water still percolates into the saturated zone, and the saturated zone, where water occupies the spaces between materials. The unsaturated zone, which extends from the surface to varying depths, contains enough spaces for water infiltration. The saturated zone, below the phreatic surface, is where water accumulates and moves slowly.

Groundwater is stored in aquifers, which are geological formations capable of storing and transmitting water. Aquifers can be classified into different types, such as free, confined and fissure, depending on the characteristics of the rocks that compose them. In porous aquifers, water is stored in the spaces created by the formation of the rocks, whereas in fissural aquifers, water circulates through the fissures in the rocks. Karst aquifers, on the other hand, have large cavities formed by the dissolution of limestone rocks (Iritani and Ezaki, 2012).

These waters can be present in igneous, sedimentary, or metamorphic rocks, and their dynamics are influenced by natural factors, such as precipitation, and by human activities, such as irrigation, which can promote the artificial recharge of aquifers. The amount of water stored underground depends on the porosity of the rocks, that is, the volume of empty spaces in relation to the total volume of the rock. Unconsolidated materials, such as sand and gravel, generally have higher porosity than more compact rocks (Iritani and Ezaki, 2012).

Another important factor that influences groundwater flow is permeability, which is the ability of water to pass through rocks. The more homogeneous the rocks are in terms of grain size and distribution, the greater the permeability and, consequently, the greater the water transmission capacity.

According to a report by the monitoring network (Imasul, 2023, p.27),

> Groundwater has chemical characteristics that are closely correlated with the rocks that store it and through which it percolates. The quality of these waters, on the other hand, can be influenced by anthropogenic activity, which is the source of punctual pollutant loads of domestic or industrial origin, and by urban and rural diffuse loads.

In Brazil, the exploitation of underground water sources represents a large part of the water supply, especially in states such as Piauí, Maranhão, Mato Grosso do Sul, Pará, Amazonas, Roraima, Tocantins, and in the western regions of São Paulo, Paraná and Rio Grande do Sul. In total, renewable groundwater reserves in the country are significant, representing a considerable part of water availability, as mentioned by Goetten; Branches; Bohn (2017).

According to a report by the monitoring network (Imasul, 2023), the Guarani Aquifer System is one of the largest aquifers in South America, covering transboundary areas between the states of Mato Grosso do Sul, Goiás, São Paulo, Paraná, Santa Catarina and Rio Grande do Sul, in Brazil, and the countries Uruguay, Paraguay and Argentina. In Mato Grosso do Sul, there is about 18% of the total area of the aquifer and 25% of the Brazilian area. This system is composed of sandy rocks from the Paraná Hydrographic Region, including the Rosário do Sul and Pirambóia Groups in Brazil, Buena Vista in Uruguay, Botucatu Formations in Brazil, as well as the Missiones Formations in Paraguay and Tacuarembó in Uruguay and Argentina. The thickness of the rocks that form the aquifer can reach up to 800 meters, being greater than 600 meters in Mato Grosso do Sul, near the municipalities of Campo Grande. The aquifer is an essential source of supply for several cities in the state, such as Campo Grande and São Gabriel do Oeste.

Extending over a vast area that covers parts of Brazil, Argentina, Paraguay and Uruguay, the aquifer occupies a significant extension in the Brazilian territory, especially in the states of São Paulo, Paraná, Mato Grosso do Sul and Minas Gerais. It is one of the main responsible for the supply of drinking water for millions of people and for agricultural and industrial activity. The groundwater of the Guarani Aquifer System is characterized by being of good quality, for the most part, with favorable characteristics for human consumption, irrigation and other uses (Goetten; Branches; Bohn, 2017; Imasul, 2023).

However, the increasing pressure on water resources and the intensification of human activities in the region, especially with the increase in agriculture, livestock and urbanization, have raised concerns about the impacts of these changes in land use and land cover on groundwater quality. Changes in land use can affect the quantity and quality of water in the aquifer, especially due to the introduction of pollutants from activities such as the excessive use of fertilizers and pesticides in agriculture, the improper disposal of industrial and urban waste, and the expansion of urban areas.

These activities have the potential to alter the ecological balance of the aquifer recharge areas, which are the regions where surface water infiltrates the soil, recharging the groundwater aquifers. Modification of these natural environments, often through deforestation, intensive monoculture cultivation or the construction of urban infrastructure, can compromise the aquifer's recharge capacity and increase the vulnerability of groundwater to contamination (Foster et al., 2013).

Therefore, understanding how these changes in land use impact the quality of groundwater in the Guarani Aquifer System/MS is fundamental for the implementation of integrated water resources management strategies. Analyzing data on land use, water quality, and agricultural and urban management practices can provide valuable insights to identify areas that are most vulnerable to water quality degradation, allowing preventive and corrective measures to be taken.

In addition, it is important to highlight that, due to the transnational nature of the Guarani Aquifer, groundwater management must be carried out in an integrated manner between the countries that share this resource. This implies the need to establish public policies and regional agreements that promote the conservation of the aquifer, encouraging sustainable land use practices, continuous monitoring of water quality, and the promotion of clean and sustainable technologies.

This study also aims to highlight the importance of educating and raising awareness among local populations about preserving groundwater quality, especially in rural and peri-urban areas, where poor management practices can have significant effects on public health and environmental sustainability.

Therefore, the environmental characterization of the Guarani/MS Aquifer System and the analysis of land use are crucial to ensure that the quality of groundwater is preserved, promoting the sustainability of water resources and water security for future generations. Knowledge of the interactions between land use and water quality is a fundamental step towards building a more efficient and responsible water management model. This article presents a detailed environmental characterization of the SAG in MS and a critical analysis of the quality of its groundwater, based on recent studies and official data.

2 METHODOLOGY

To carry out this article, qualitative and quantitative methodological approaches were used. This methodology allowed a comprehensive and integrated analysis of the theoretical, legal and empirical aspects related to the quality of groundwater in the Guarani Aquifer System (SAG) in Mato Grosso do Sul.

2.1 METHODOLOGICAL PROCEDURES

The work was developed in three stages (Table 1): in the first stage, bibliographic surveys were carried out, through documentary research (books, dissertations, scientific articles, newspaper articles, internet sites, etc.) on groundwater in Mato Grosso do Sul and the Guarani Aquifer System (SAG), as well as the legal aspects of groundwater in Brazil and Mato Grosso do Sul.

The second stage of the study was carried out with the acquisition of secondary data from the Institute of Environment of Mato Grosso do Sul (IMASUL) on the quality of groundwater in the Aquifer, through the Monitoring Network (2018 to 2022) as well as digital map files (shapefiles).

Finally, the integration and cartographic compilation made through the ArcGIS software, with integrated analysis of all the highlighted variables based on the proposed objectives.

Contextualize the theme based on theoretical, technical and legal foundations.

- **Sources consulted: Academic:** Indexed scientific articles (Scopus, Web of Science, SciELO, Google academic etc...), theses, dissertations and technical books on hydrogeology, groundwater quality and water resources management.
- **Legal:** Federal legislation (Law No. 9,433/1997 – National Water Resources Policy); State standards (CONAMA Laws and Resolutions on the granting and monitoring of groundwater)
- **Institutional:** Technical reports from **ANA (National Water Agency), CPRM (Geological Service of Brazil) and IMASUL.**
- **Open media and databases:** Complementary data from environmental agencies and platforms such as **SNIRH (National Water Resources Information System).**

- **Selection criteria:**

✓ Prioritization of publications from the last **5 years** (2018–2022), except for legal frameworks and classical studies.

Collection and Processing of Secondary Data

Obtain representative data of the water quality of the SAG in the state.

- **Secondary Data Sources:**

✓ **IMASUR:** Data from the **Groundwater Monitoring Network** (2018–2022), including:

(a) Physicochemical parameters (pH, conductivity, turbidity).

(b) Concentrations of major ions (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, SO_4^{2-}) and contaminants (NO_3^{-}, heavy metals).

(c) Data from monitored wells (location, depth, flow).

✓ **Georeferenced shapefiles**: SAG boundaries, hydrogeological units, and land use maps.

✓ **Data processing:**

1- **Quality control:** Elimination of inconsistent data (missing or non-standard values).

2- **Normalization:** Conversion of units to **CONAMA 396/2008 standards**.

- **Organization:** Creation of structured spreadsheets (Excel) for statistical analysis.
- **Spatial Analysis and Integration of Results**

Correlate hydrochemical data with geographic and anthropogenic factors. **Tools used: ArcGIS 10.8:** For: Thematic mapping (distribution of chemical parameters).

3 RESULTS AND DISCUSSION

The **Guarani Aquifer**, recognized by UNESCO (2009) as one of the largest transboundary aquifer systems in the world, is extremely relevant for Mato Grosso do Sul, supplying about **79 municipalities** (ANA, 2020). Studies by the IBGE (2022) indicate that approximately **70% of the state territory** is under its area of occurrence, making it crucial to analyze the relationships between land use patterns and the dynamics of this water resource.

In the state, **agriculture,** especially the cultivation of soybeans, corn and sugarcane, occupies extensive areas that coincide with strategic recharge zones. Data from MapBiomas (2023) show that this activity has expanded **by 40% in the last decade**, while research from Embrapa (2021) warns that **30% of these areas** have a moderate to high risk of contamination by pesticides and nitrates. At the same time, **extensive cattle ranching**, another regional economic pillar, contributes to soil compaction, reducing **its infiltration capacity by up to 50%** (Foster et al., 2020).

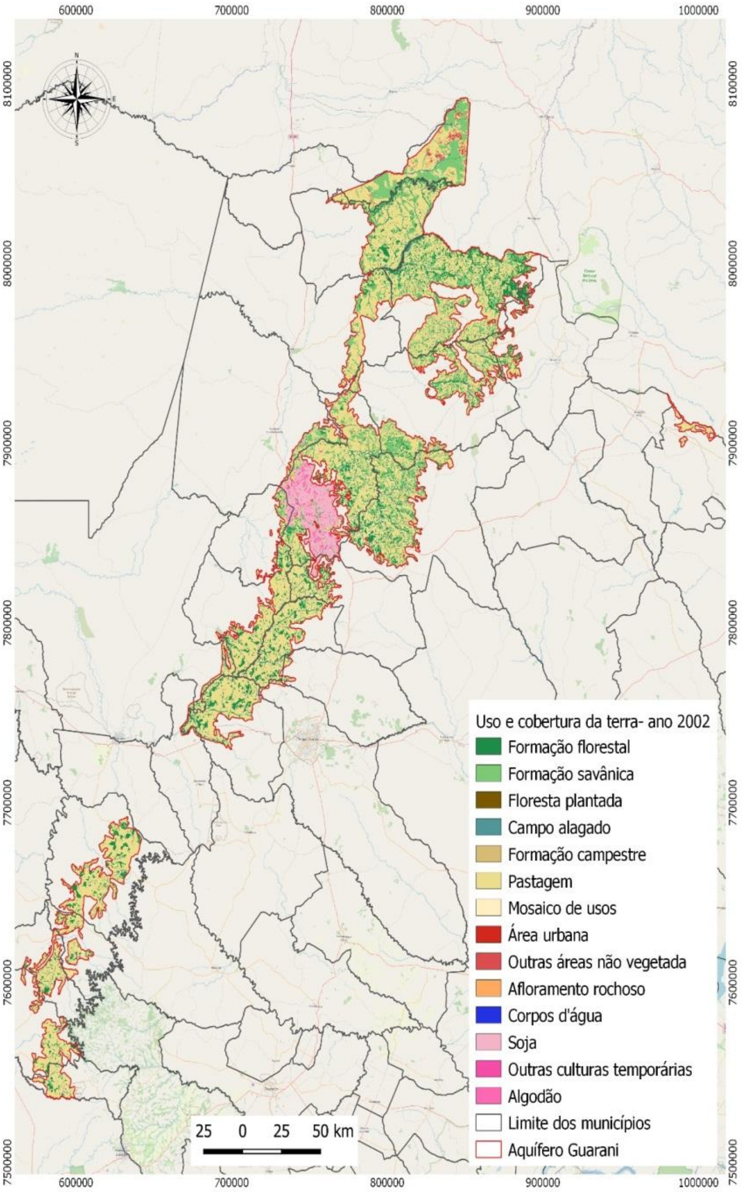
Urban **growth** also exerts significant pressure on the aquifer. Municipalities such as Dourados, Ponta Porã, and Maracaju, which develop on the Guarani Aquifer, have expanded **by 25% in the last 15 years** (Ministry of Cities, 2023). A study by UFMS (2022) identified that **60% of soil waterproofing** occurs precisely in the recharge zones, aggravated by the fact that only **45% of municipalities** have adequate basic sanitation systems, increasing the risks of groundwater contamination.

Native **vegetation**, especially remnants of Cerrado and Atlantic Forest, plays a key role in protecting the aquifer. However, data from Probio (2022) show that the **Cerrado in the state has lost 18% of its cover** in the last two decades, while the **Permanent Preservation Areas (APPs)** have a deficit of **35%.** In addition, **eucalyptus and pine forest plantations** in recharge areas, although economically relevant, alter the local water balance, reducing the volumes destined to aquifer recharge due to higher water consumption (ANA, 2022).

Faced with these challenges, initiatives such as the **Guarani Aquifer Project (SAG, 2018)** and the **State Water Resources Plan (2021)** have been implementing measures such as the **zoning of 40% of the recharge areas**, good agricultural practices programs on **1,200 properties,** and a monitoring network with **120 observation wells**. UNESCO-IHP (2021) reinforces that the sustainability of the aquifer depends on the **expansion of these actions**, the implementation of **sustainable land use policies,** and the strengthening of **transboundary governance**.

Figure 1

Land use and land cover in 2002 of the Guarani Aquifer/MS



Source: MapBiomas, 2023

The **land use and land cover map (2002)** presents a diversity of categories, including plant formations (forest, savannah, and grassland), agricultural areas (pasture, soybean, cotton), urbanized zones, and water bodies, highlighting the complexity of territorial occupation and the need for integrated management to preserve the Guarani Aquifer.

Table 1 shows that the pasture use class comprises 54.8% of the Aquifer area, followed by forest formation with 16.7% and savanna formation with 13.6%.

Table 1

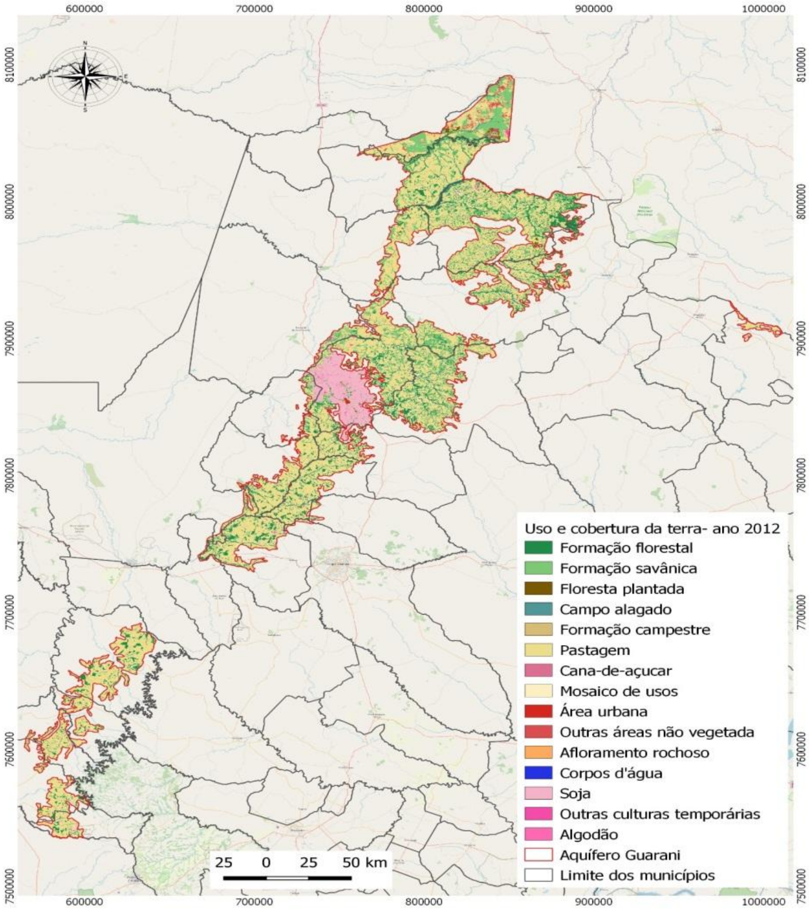
Quantification of Land Use and Land Cover Classes in 2002 of the Guarani Aquifer/MS

Land use and land cover classes 2002	Km2	%
Forestry training	3.586,8	16,7
Savannah formation	2.917,1	13,6
Planted forest	5,2	0,0
Flooded field	499,9	2,3
Countryside training	62,1	0,3
Pasture	11.759,0	54,8
Sugar cane	0,0	0,0
Mosaic of uses	1.283,7	6,0
Built-up area	16,7	0,1
Other non-vegetated areas	123,6	0,6
Water Bodies	49,8	0,2
Soy	937,1	4,4
Other temporary crops	74,2	0,3
Cotton	133,9	0,6
Total	21.449,1	100

Source: MapBiomas, 2023

Figure 2

Land use and land cover in 2022 of the Guarani Aquifer/MS



Source: MapBiomas, 2023

Between 2002 and 2022, there was a downward trend in natural formations (forests and savannahs) and pastures, while there was an increase in agricultural cultivation areas (especially soybean and planted forests) and in the mosaic of uses (Table 6). Urban sprawl was modest, but non-vegetated areas increased, possibly due to land degradation or infrastructure expansion. The decrease in water bodies is worrying and may be related to climate change or unsustainable use of water resources.

These changes reflect increasing pressure on land use, with agricultural expansion and the fragmentation of natural ecosystems. This reinforces the need for territorial planning policies that promote a balance between agricultural production, environmental conservation, and sustainable urban development.

The Guarani Aquifer, one of the largest underground freshwater reservoirs in the world, faces increasing pressures due to changes in land use and land cover in recent decades. These impacts, direct and indirect, threaten its availability and quality, putting at risk the supply of millions of people and the sustainability of essential economic activities.

It was observed that the expansion of crops such as soybeans and sugarcane has increased the use of fertilizers and pesticides, which infiltrate the soil and reach the water table. Recent studies, such as those by Embrapa (2023) and **Cerdeira et al., 2008,** have already detected the presence of nitrates and glyphosate in wells near agricultural areas, indicating a real risk of groundwater contamination. If left unchecked, this process can make human consumption unfeasible without expensive and complex treatments.

Large-scale irrigation, especially in crops such as sugarcane and soybeans, reduces the natural recharge of the aquifer. In regions such as Ribeirão Preto (SP**),** the level of the Guarani Aquifer has already dropped 15 meters in 20 years (ANA, 2022), an alarming sign that extraction is exceeding the capacity for renewal. If this pace continues.

Table 2

Quantification of Land Use and Land Cover Classes in 2002 of the Guarani Aquifer/MS

Land use and land cover variation between 2002 and 2022	**2002**	**2012**	**2018**	**2022**	**2002-2022**
Forestry training	16,72	15,73	15,72	15,38	-1,3%
Savannah formation	13,60	11,96	11,79	11,20	-2,4%
Planted forest	0,02	0,38	0,83	0,92	+0,9%
Flooded field	2,33	2,33	2,41	2,55	+0,2%
Countryside training	0,29	0,52	0,69	0,79	+0,5%
Pasture	54,82	55,41	53,98	52,13	-2,7%
Sugar cane	0,00	0,00	0,01	0,01	+0,01%
Mosaic of uses	5,98	6,75	7,32	8,83	+2,85%
Built-up area	0,08	0,10	0,10	0,11	+0,3%
Other areas do not veget.	0,58	0,60	0,60	1,14	+0,56
Water Bodies	0,23	0,22	0,19	0,18	-0,05
Soy	4,37	5,28	6,02	6,59	+2,22%
Other crops temp.	0,35	0,60	0,27	0,19	-0,16%
Cotton	0,62	0,12	0,04	0,00	-0,62%
Total	100,00	100,00	100,00	100,00	

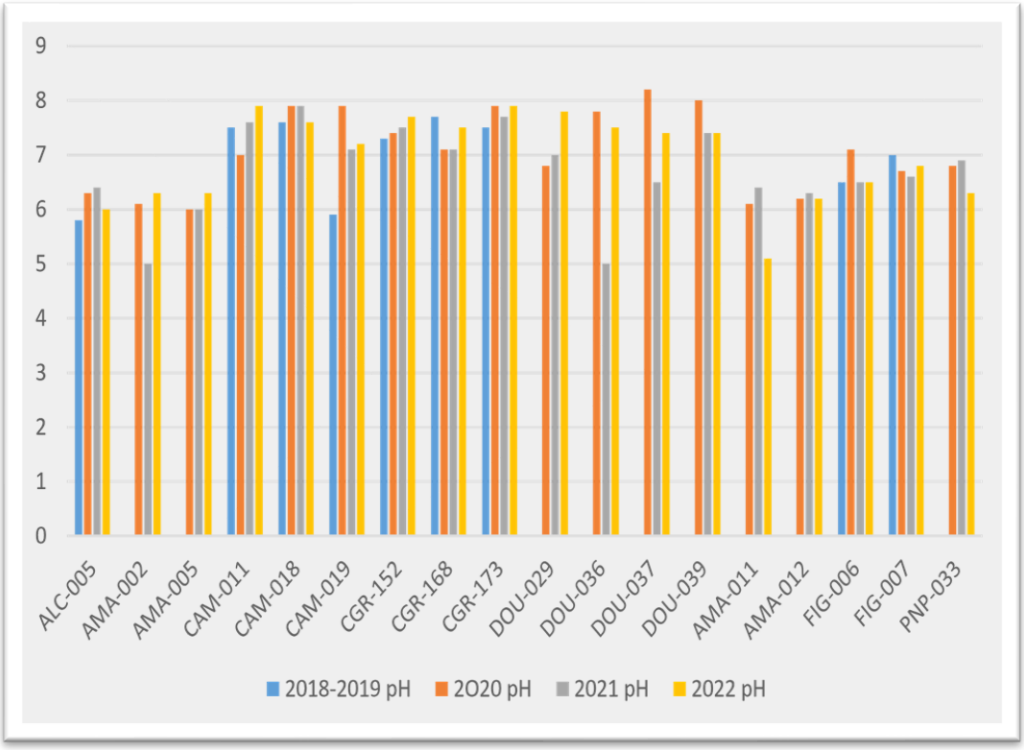
Source: MapBiomas, 2023

3.1 WATER QUALITY MONITORING AT SAG/MS – 2018 TO 2022

The monitoring of water quality in the SAG/MS is carried out by IMASUL using physical-chemical and biological parameters. These are easily measurable and useful parameters to see the evolution of the most dominant chemical elements in the waters of the wells in the study area, their concentrations and their origins. The physicochemical and biological parameters analyzed are as follows:

Figure 3

Hydrogen potential (pH) between the years 2018-2022 in the underground wells of the State of MS

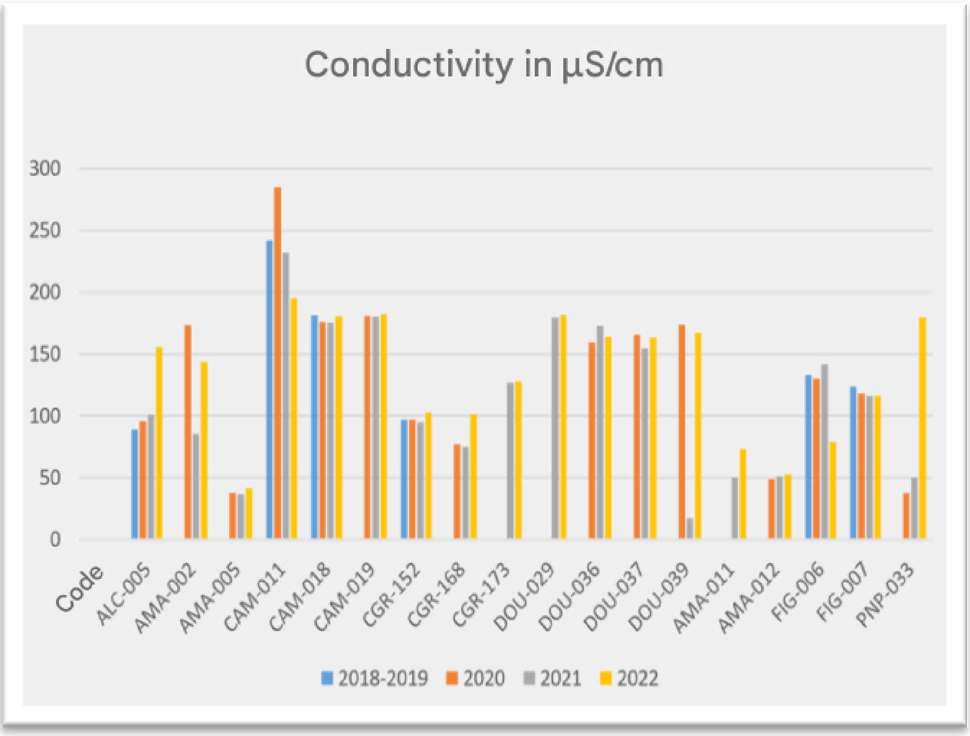


Source: MapBiomas, 2023

The pH is a physical parameter that determines the acidity or alkalinity of a solution, and is measured by a pH meter. According to data from Imasul (2018-2022), we observed the minimum value recorded was **pH 5** (in the AMA-002 and DOU-036 drillings), while the maximum reached **pH 8.2** (DOU-037 drilling). However, according to **CONAMA resolution No. 396/2008,** there is no limit value allowed for pH in fresh waters. Thus, the results indicate that most of the measurements exceed the established standards, signaling the need for evaluation of the water quality in these locations.

Figure 4

Electrical conductivity between the years 2018-2022 in the underground wells of the State of Mato Grosso do Sul



Source: MapBiomas, 2023

3.2 ELECTRICAL CONDUCTIVITY

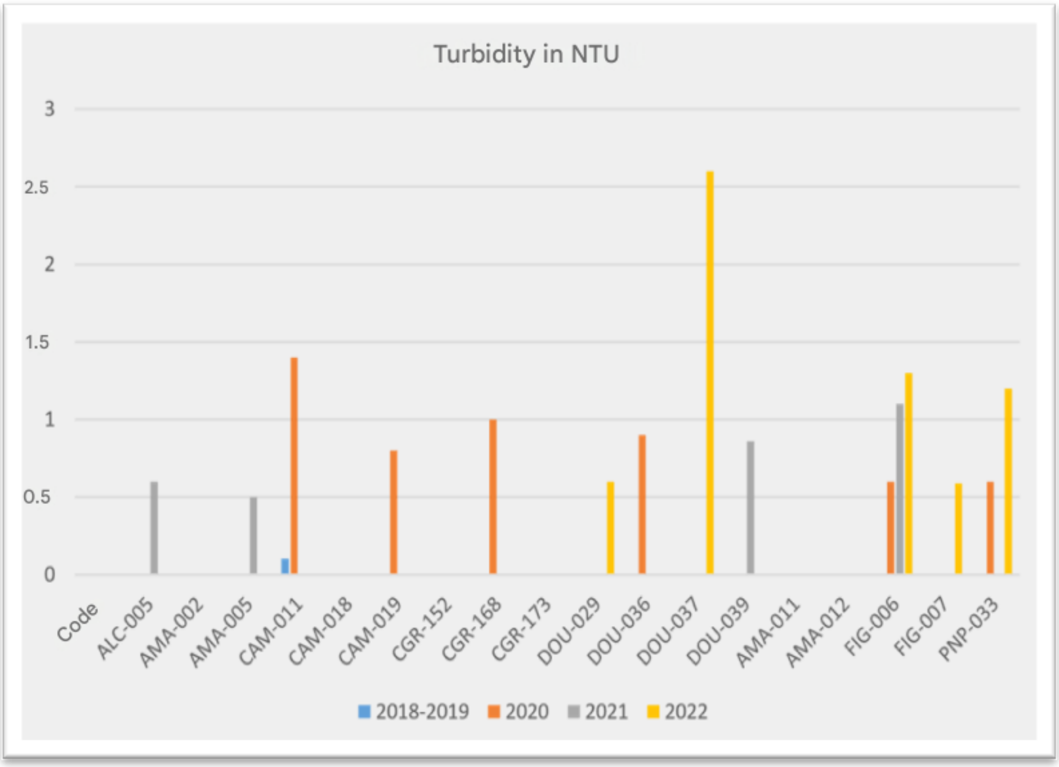
According to (Blanco, 2017), the measurement of electrical conductivity provides information about the mineralization of water. It increases with increasing dissolved salt content in the water.

The variation in water mineralization is governed by several factors:

- Significant evaporation linked to surface approach
- Residence time and water exchange around
- General Direction of Groundwater Flow
- Exchanges with adjacent groundwater

Figure 5

Turbidity between the years 2018-2022 in the underground wells of the State of MS



Source: MapBiomas, 2023

The turbidity of a source is caused by the presence of suspended matter or substances in solution, such as mineral substances (sand, clay or silt), organic matter (dead organic matter or decaying plants, etc.) or other microscopic materials that form an obstacle to the passage of light in the water.

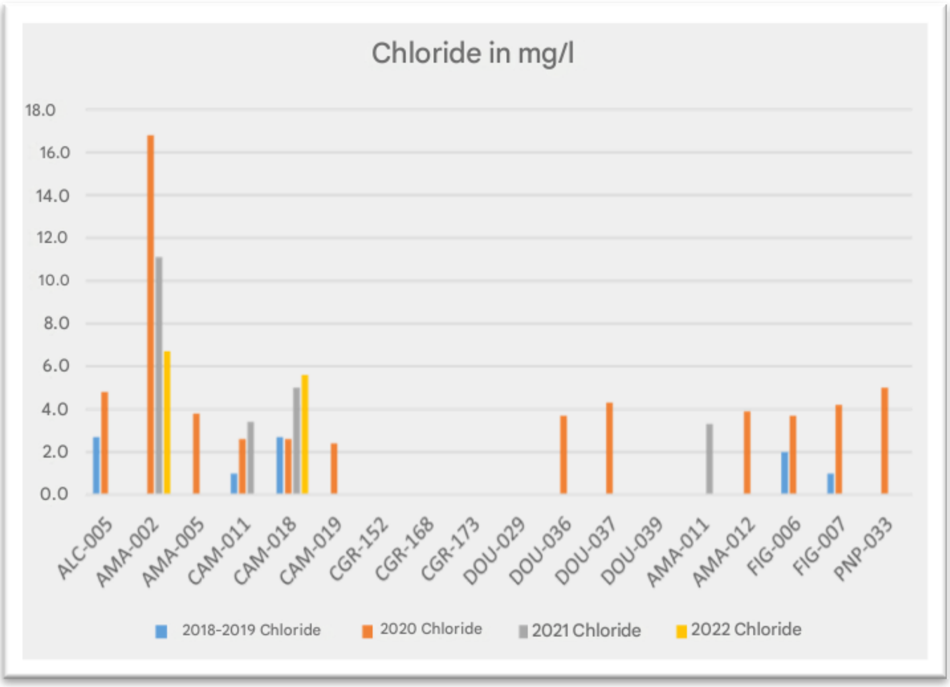
In our case, the values recorded in the 19 wells between 2018 and 2022 by IMASUL(2023) with turbidimetry vary between the values <0.5 NTU to 2.6 NTU. According to the WHO, the turbidity values must be less than 5 NTU, so we can say that all the drillings collected in 2018-2022 comply with WHO standards

3.3 DISSOLVED OXYGEN

Dissolved oxygen (DO) in water is crucial for maintaining the quality of the environment, the health of aquatic ecosystems, and water treatment, and is essential in biological processes such as wastewater treatment and drinking water production, but it can also cause oxidation damage to industrial equipment, such as steam generation. The WHO recommends a minimum of 5 mg/L of DO for drinking water, while CONAMA establishes 6 mg/L as the lower limit, and ideal levels can range between 8-10 mg/L to ensure adequate quality and compliance with environmental regulations.

Figure 6

Chlorides between the years 2018-2022 in the underground wells of the State of MS



Source: MapBiomas, 2023

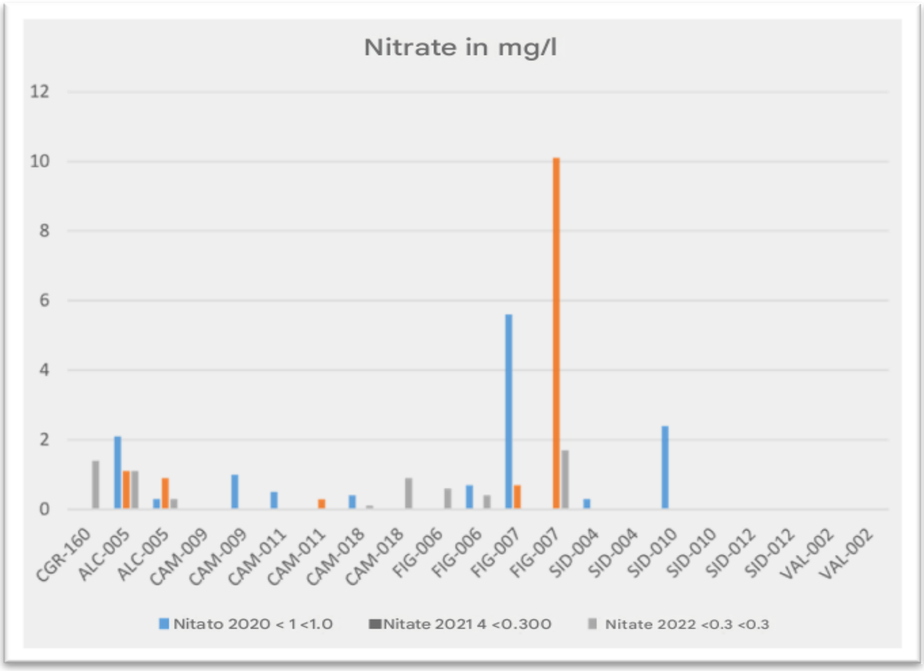
3.4 CHLORIDES

We observed that chlorides are always present in natural waters in very variable proportions, their presence in groundwater results from the dissolution of natural salts, by the dissolution of sylvite (KCl) and halite (NaCl).

Data collected in the period from 2018 to 2022 according to a report by Imasul (2023) show that chloride values vary from one well to another with a minimum of less than (2.3 and 2.5) mg/l Cl2 in CGR-152; CGR-168; CGR-173; DOU-029; DOU-039; on the other hand, the maximum is 16.2 mg/l of Cl2, in well AMA-002 (Figure 6). According to CONAMA No. 396/2008, the limit value must be equal to 250 mg/l

Figure 7

Nitrates between the years 2018-2022 in the underground wells of the State of MS Nitrate (NO3)



Source: MapBiomas, 2023

Basically, nitrates present in water have several forms, such as:

- Biological fixation
- Precipitation
- Mineralization of plant and animal residues and soil organic nitrogen.

The development of human activities has modified the natural cycle of nitrogen, considerably increasing the amounts involved (Who, 2011; Fetter, 2001).

The quality limit is set at 50mg/l of nitrates in the supply water. It is based on the recommendations of the World Health Organisation (WHO). We observed that the nitrate contents in the groundwater of the study area for the periods from 2018 to 2022 are between values below 0.23 mg/l and a maximum value of 10.1 mg/l. In 2021, the AMA002 well had a nitrate value of 10.1 and in 2022, the ALC-005 well had a value of 14.8, in disagreement with CONAMA Resolution 396/2008, which has a maximum acceptable value of 10.0 (figure 7).

3.5 POTENTIAL SOURCES OF CONTAMINATION OF WATER RESOURCES IN THE SAG/MS

Regarding the non-conformities of CONAMA Resolution 396/2008, the presence of total coliforms was observed in wells CAM-018, FIG-006, DOU-036 and AMA-011, E-coli in DOU-036 and nitrate in ALC-005, in 2022. In 2021 total coliforms in CAM-011. In 2020, total coliforms in ALC-005 and AMA-002. In 2018-2019 CGR 160 and SID-004

(Table 3).

Nitrate is the main source of pollution that is widespread in groundwater, due to its high mobility it is recognized worldwide, and its origin is linked to human activities. Waters with high levels of nitrate contamination are a more distant sign of pollution, as it is the product of nitrogen oxidation.

Nitrates in groundwater come mainly from four sources:

a) Application of nitrogen fertilizers, other inorganic chemicals, and manure animal, in plantations;

b) farming;

c) human waste water deposited in septic tanks and atmospheric deposits (Blanco, 2017).

Table 3

Summary table of the results of groundwater quality of the SAG in 2018-2019, in the State of Mato Grosso do Sul.

	2018-2019		**2020**		**2021**		**2022**		**2018-2022**
Parameter	Min. value	Max. value	Min. value	Max. value	Min. value	Max. value	Min. value	Max. value	
ph	5.2	8.3	6.0	8.2	5.0	7.9	5.1	7.9	5.0 – 8.3
Contentibility	30	243.7	37.9	285.0	17.3	232.0	41.3	195.0	17.3-285.0
Turbidity	0.1	3.3	<0.5	1.4	<0.5	1.09	<0.5	2.62	0.1 – 3.3
Nitrates	0.3	3.7	<0.05	5.60	<0.23	10.1	0.11	14.8	0.05 - 14.8
Hardness	16	140	15.6	132.8	14.8	123.2	13.7	86.7	13.7 - 140
Coliforms Total	Presence 2 samples		Presence 2 samples		Presence 1 sample		Presence 4 samples		

E.Coli	Presence 01 sample	---	---	Presence 1 samples	

Source: Imasul, 2023

According to Camponogara et al. (2006), groundwater is a vital resource, often underestimated, but of great environmental, social and economic relevance, presenting superior quality to surface water due to its natural protection against pollutants, provided by rocks and sediments that act as filters, reducing treatment costs. However, human activities have degraded its quality, leading to contamination by toxic and persistent substances, often introduced by infiltration into the soil, putting its sustainability and safety at risk.

4 FINAL CONSIDERATIONS

The study on environmental characterization of the Guarani/MS aquifer system and analysis of groundwater quality (2018-2022) revealed significant changes, such as the reduction of natural areas (forests and savannahs) due to agricultural (soybean, sugarcane, and planted forests) and urban expansion, impacting biodiversity and water resources. Although pastures still dominate, their decrease reflects the conversion to crops. Groundwater quality varied, with acceptable pH and conductivity levels, but nitrate (from fertilizers) and coliforms (sewage/manure) contamination in some wells, requiring improvements in sanitation. The study highlights the need for sustainable management, responsible agricultural practices, and continuous monitoring to balance economic development, environmental conservation, and water security, ensuring the protection of the aquifer for future generations.

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