ABES

Revista Brasileira de Ciências Ambientais
Brazilian Journal of Environmental Sciences

Nitrate in drinking water in rural communities in Goiás, Brazil

Nitrato em água de consumo humano em comunidades rurais de Goiás, Brasil

Ana Carolina Borges Ramos[1], *Paulo Sérgio Scalize*[1]

ABSTRACT

Access to safe drinking water is a fundamental human right, yet rural communities often face challenges related to nitrate contamination, posing risks to public health. This study assessed the presence of nitrate and health risks in 24 rural communities in the state of Goiás, Brazil. A total of 158 water samples from surface and groundwater sources were analyzed to determine nitrate concentrations, Hazard Quotient (HQ), and Hazard Index (HI). Nitrate was detected in 60.1% of the samples, with concentrations ranging from non-detectable to 11.6 mg/L, with the highest levels having being observed in shallow wells. Although mean HQ and HI values remained below 1.0, maximum values exceeding this threshold were recorded in hand-dug and shallow tube wells, indicating increased health risk. Communities relying on individual water supply solutions and characterized by inadequate sanitation infrastructure exhibited the poorest indices. Rudimentary pit latrines were present in 70.8% of the communities, and 29.2% had distances shorter than 45 m between latrines and water abstraction points, increasing the potential for cross-contamination. Animal excreta in household yards were identified in 16 communities, further exacerbating water vulnerability. The poorest results were associated with the use of wells as the primary water source, with a predominance of shallow hand-dug wells in Lageado (11 of 13 samples) and shallow tube wells in Olhos d'Água. Overall, the findings indicate a higher risk of nitrate contamination in individual water supply systems, particularly in rural settlements and where pit latrines are located near abstraction points. In contrast, surface water sources and collective supply systems showed lower nitrate concentrations, below health risk thresholds, underscoring the need for continuous monitoring — especially in communities with HI>1.0 — and for the implementation of preventive and educational measures.

Keywords: risk indicator; diffuse pollution; chemical risk; rural sanitation; hazard index; shallow dug well; shallow tubular well; rudimentary septic tank.

RESUMO

O acesso à água potável é um direito fundamental, mas comunidades rurais ainda enfrentam desafios relacionados à contaminação por nitrato, comprometendo a saúde humana. Este estudo avaliou a presença de nitrato e os riscos à saúde em 24 comunidades rurais no estado de Goiás. Foram analisadas 158 amostras de água de mananciais superficiais e subterrâneos, determinando-se as concentrações de nitrato, o Hazard Quotient (HQ) e o Hazard Index (HI). Detectou-se nitrato em 60,1% das amostras, variando de "não detectado" a 11,6 mg/L, com as maiores concentrações em poços rasos. Embora as médias de HQ e HI tenham permanecido abaixo de 1,0, valores máximos superiores foram registrados em poços escavados e tubulares rasos, indicando maior risco à saúde. Comunidades com soluções individuais e infraestrutura sanitária precária apresentaram os piores índices. A presença de fossas rudimentares foi observada em 70,8% das comunidades, e 29,2% apresentaram distância inferior a 45 m entre fossa e captação de água, aumentando o risco de contaminação cruzada. Excretas de animais no quintal foram identificadas em 16 comunidades, agravando a vulnerabilidade hídrica. Observou-se que os piores resultados estão associados ao uso de poços como principal fonte de abastecimento, com predominância de poços rasos escavados em Lageado (11 de 13 amostras) e de poços tubulares rasos em Olhos d'Água. Os dados indicam maior risco de contaminação por nitrato em soluções individuais de abastecimento, especialmente em assentamentos rurais e na presença de fossas próximas às captações. Em contraste, mananciais superficiais e sistemas coletivos apresentaram menores concentrações, abaixo dos limites de risco à saúde, reforçando a necessidade de monitoramento contínuo, sobretudo em comunidades com HI>1,0, e da adoção de ações preventivas e educativas.

Palavras-chave: indicador de risco; poluição difusa; risco químico; saneamento rural; hazard index; poço raso escavado; poço tubular raso; fossa rudimentar.

[1]Universidade Federal de Goiás – Goiânia (GO), Brazil.

Corresponding author: Ana Carolina Borges Ramos. Federal University of Goiás, Avenida Universitária, Q. 86 – Setor Leste Universitário – CEP: 74605-220 – Goiânia (GO), Brazil. E-mail: ana.borgesramos@outlook.com

Received on: 04/26/2025. Accepted on: 02/25/2026.

https://doi.org/10.5327/Z2176-94782577

Introduction

According to the United Nations Organization (ONU, 2019), the right to drinking water and basic sanitation access is essential for human dignity, and must be ensured to everyone. In that sense, one of the Sustainable Development Goals (SDG) seeks to guarantee, until 2030, the equitable and universal access to these resources, reinforcing the importance of global actions to face the challenges imposed by the lack of sanitation and good quality water to public health and the environment (ONU, 2019). The absence of the aforementioned services jeopardizes the well-being of population and environmental sustainability, which turns the adoption of effective measures into an urgent matter.

In Brazil, demographic changes that occurred throughout the 20th century, propelled especially by the rural exodus and the advancement of urbanization, have intensified the pressure over the water supplying urban systems, while rural areas remained with deficient structure. This demographic shift has highlighted structural inequalities between the urban and rural contexts, especially in regard to the access to drinking water and basic sanitation (Brasil, 2019). Rural communities, especially, face significant challenges concerning water quality, since many are located in isolated areas of difficult access (Galezzo and Rodríguez Susa, 2021; Silveira et al., 2024), which increases the difficulty for the implementation of adequate water supplying systems. In these areas, dependence on individual sources, such as springs (Scalize et al., 2014; Rukavishnikov et al., 2024), rainwater cisterns (Scalize et al., 2021; García-Ávila et al., 2023) and underground wells (Scalize et al., 2014; Braimah et al., 2021; Lopes et al., 2023; Stokdyk et al., 2025) is a common occurrence, although these do not always guarantee the potability of water. Furthermore, the intensification of agricultural activities, marked by the growing use of fertilizers and other agrochemicals, has contributed to the contamination of hydric resources (Bijay-Singh and Crasell, 2021; Campbell et al., 2023). Studies show that this sort of contamination increases the levels of nitrate, ammonia and fecal coliforms, besides reducing dissolved oxygen, which further compromises the quality of water available for human use (Alfarisy et al., 2020). This increases the risks of waterborne diseases, affecting the health and development of these populations. In that sense, it is fundamental to analyze the rural reality based on its specificities, for instance by means of case studies. Evaluations that consider the physical, chemical and microbiological parameters of water are essential to estimate the sanitary vulnerability of the exposed populations, as can be seen in several research papers (Islam et al., 2021; Zhang et al., 2021; Assis et al., 2022; Braga et al., 2022; Scalize et al., 2022; Rezende et al., 2023; Abdipour et al., 2025).

Among these contaminants, nitrate sets itself apart due to its high solubility and mobility, which makes it a pollutant of high reach, both in surface and underground waters. Besides being the result of the intensive use of fertilizers, nitrate is also associated with lack of basic sanitation, since the inadequate disposal of domestic effluents and slurry contribute to its presence in water, often accompanied by pathogenic microorganisms (Qasemi et al., 2018; Freitas et al., 2001; Oliveira, 2023). The presence of nitrate in water might be related to the weaknesses in responsibility and accountability regarding water supply (Prickett et al., 2023), demanding more attention from managers.

The main channel of human exposure to nitrate is the ingestion of contaminated water and food. In higher concentrations, nitrate can be converted to nitrite in an organism, which oxidizes hemoglobin and methemoglobin, compromising oxygen transportation in blood. The consequences of such include symptoms such as a reduction of oxygen to tissues, artery pressure drop, an increase in cardiac rhythm, abdominal cramps and vomit, with the possibility of being fatal (Wang et al., 2022; Yang et al., 2022; Zakaria et al., 2022; Pinheiro, 2023).

Considering these risks, the use of tools which allow the evaluation of the impact of ingestion of contaminated water in human health is essential. Among the available methods, Hazard Quotient (HQ) and Hazard Index (HI) stand out; these are indicators used to estimate the non-carcinogenic risk from the relation between exposure dose and reference values that are considered safe (USEPA, 1989; Eggers et al., 2018; Zhang et al., 2021).

Therefore, the goal of the present study is to evaluate the environmental risk related to the consumption of water in rural communities, through analysis of the concentrations of nitrate in different hydric sources and the application of HQ and HI indices, in order to identify potentially vulnerable populations.

Materials and Methods

Area of study

The study was conducted in 24 rural communities in the State of Goiás, involving 13 *quilombola* communities, four riparian communities and seven agrarian reform settlements (Chart 1). These communities are situated in the state of Goiás, they belong to the Brazilian Cerrado biome (Rodrigues et al., 2022), and have been selected in the scope of the "*Environmental Sanitation and Health in Rural and Traditional Communities of Goiás — SanRural*" Project (Projeto SanRural, 2021-2022).

Sample collection nitrate analysis and data treatment

The water samples were collected between September 2019 and October 2020, stemming from different supply sources: rainwater cisterns (19), excavated shallow wells (47), shallow tube well (31), deep tube well (28), headwaters (17) or springs (16). The collection was conducted in a timely manner in the aforementioned sources, being properly secured, and the samples were preserved under refrigeration and individually analyzed. All the procedures of collection, preservation and determination of nitrate were conducted according to ultraviolet (UV) spectrophotometry as described in the *Standard Methods for the Examination of Water and Wastewater* (APHA et al., 2022).

Additionally, in the moment of visitation, the number of families in each community was surveyed.

All the results, as well as the average and median concentrations, were tabulated in an electronic spreadsheet and analyzed according to the source of consumption, and the type of supplying system (water supply systems — WSS and individual supply solution — ISS). Lastly, the communities in which the nitrate values extrapolated the concentration limits of 10 mg/L were detected, based on the limit established by the United States Environment Agency (USEPA, 2024), as well as Annex XX of the Ordinance of Consolidation n. 5, updated by Decree GM/MS N. 888 (Brasil, 2021).

Hazard quotient and hazard index

Considering the nitrate results obtained for the 158 samples analyzed, HQ and HI were determined for two distinct scenarios: type of water supply source used for human consumption; and water consumed by the community, irrespective of source. HQ determination was done in light of the demographic group, using reference values (Table 1).

From the results of daily ingestion, a comparison of the results with the Reference Dose (RfD) was conducted (Equation 1).

$$HQ = \frac{CDI}{RfD} \quad (1)$$

In which:

CDI: Chronic Daily Intake (mg/kg/day);

RfD: Reference Dose for the contamination channel chosen according to the demographic group (adult, children, baby) (mg/Kg/day), also defined as Acceptable Daily Ingestion (ADI) by Brazil's Health Surveillance Agency (ANVISA).

Both HQ e and HI were determined in the places where nitrate was detected, irrespective of quantity. For that, calculations were made to determine the estimated daily ingestion of the population exposed to risk (Equation 2).

$$CDI_{oral} = \frac{C_w * \ IR * EF * ED}{BW * \ AT} \quad (2)$$

Chart 1 – Names of the analyzed communities, with its respective municipalities and typology.

Community	Municipality	Community	Municipality
Arraial da Ponte (R)	Água Limpa	Pouso Alegre de Goiás (A)	Mineiros
Baco Pari (Q)	Posse	Povoado Moinho (Q)	Alto Paraiso de Goiás
Canabrava (Q)	Flores de Goiás	Povoado Verissimo (R)	Goiandira
Castelo Retiro Três Rios (Q)	Simolândia	Povoado Vermelho (Q)	Niquelândia
Extrema (Q)	Iaciara	Rochedo (A)	Professor Jamil
Forte (Q)	São João da Aliança	Santa Fé da Laguna (Q)	Barro Alto
Itajá 2 (A)	Goianesia	São Domingos (Q)	Cavalcante
João de Deus (A)	Silvânia	São Lourenço (A)	Uruaçu
Lageado (A)	São Miguel do Araguaia	São Sebastião da Garganta	Silvânia
Landi (R)	Nova Crixás	Sumidouro (Q)	Padre Bernardo
Olhos d'Água (R)	Gameleira	Taquarussu (Q)	Campos Belos
Pelotas (Q)	Monte Alegre de Goiás	Vazante (Q)	Divinopolis de Goiás

Q: *quilombola* community; A: agrarian reform settlement; R: riparian community.

Table 1 – Parameters considered for the Hazard Quotient calculation, with its respective reference values regarding the age range of the analyzed population.

Parameters	HQ Factor	Adult (>19 years old)	Child (6 to 12 years old)	Baby (<1 year old)	Source
Ingestion Rate	IR (L/day)	2	1,5	0.8	USEPA (1989)
Exposure Frequency	EF (days/year)	365	365	365	USEPA (1989)
Exposure Duration	ED (year)	70	10	1	USEPA (1989)
Average Individual Body Weight*	BW (kg)	70	20	10	USEPA (1989)
Average time of exposure to the contaminant	AT (days)	14600	3650	365	USEPA (1989)
Reference Dose	RfD (mg/kg/day)	1.6	1.6	1.6	Qasemi et al. (2018)

*For communities above the maximum nitrate concentration value, calculations using the real average weight of the community were made.

In which:
CDI: Chronic Daily Intake (mg/kg/day);
Cw: concentration of contaminant in the potable water (mg/L);
BW: average individual body weight (kg);
AT: average time of exposure to the contaminant (days);
IR: Ingestion Rate (L/day);
EF: Exposure Frequency (days/year);
ED: Exposure Duration (year);
ET: Exposure Time (h/day).

Based on this comparison between chronic daily intake and reference dose, the HQ was obtained, which must be inferior to 1.0 in order to indicate no risk of health effects. If its value is above 1.0, it is concluded that the potential negative effects to health are increased, although this does not mean that such effects will inevitably appear (USEPA, 1989). Using the results obtained in equation 1, HI was determined as the sum of the HQs (Equation 3).

$$HI = HQ_1 + HQ_2 + \cdots + HQ_n \quad (3)$$

After the HQ calculation, with the help of an electronic spreadsheet, the results for each age range were compared among each other, as were the limits established by USEPA with the Brazilian law of 10 mg/L.

Lastly, the HQ and HI results for each nitrate concentration were grouped in two manners for a better understanding of the two distinct scenarios, one analysis being made according to the rural community, and another according to the water source for human consumption.

Contamination sources

In the present study, possible contamination sources were identified; the presence of a septic tank, rudimentary cesspit or direct disposal in water bodies; the existence of animal excreta in the terrain; and a distance between the water source and rudimentary cesspit below 45 m.

The results were then recorded in a spreadsheet and analyzed descriptively with regard to the presence of nitrate in the water supply sources.

Results

Presence of nitrate in function of the water supply source

The 158 results regarding nitrate (Appendix 1) pointed to its presence in 60.1% of the samples (95/158). They were distributed as a function of the supply source and type of system, 16 of which being related to a WSS (three from headwater, 12 from a deep tube well and one a shallow tube well), and 142 to an ISS (19 cisterns, 16 from a surface spring, 14 from headwater, 47 from an excavated shallow well, 16 from a deep tube well and 30 from a shallow tube well).

Considering all samples, the nitrate concentrations vary from "undetected" up to 11.6 mg/L, with a variation coefficient of 16 to 64% (Table 2), very high dispersion (CV>30%) for cistern water (rainwater), average dispersion for excavated wells (10%<CV≤20%) and high dispersion (20%<CV≤30%) for the other sources (Pimentel-Gomes, 1987).

The greatest dispersion observed in the nitrate concentrations were seen in rainwater cisterns (CV=64%), varying from 0.1 to 2.1 mg/L (Table 2 and Figure 1). This fact might be related to the lack of maintenance and periodical cleaning of these structures, as reported in other studies which have highlighted the importance of regular cistern cleaning in order to avoid the contamination of stored water (Santos et al., 2023).

It was also possible to observe a variability in nitrate concentrations according to the water supply source (Figure 1a). The greatest concentrations were observed in well water. In excavated shallow wells and tube shallow wells, the maximum values of 9.7 and 11.6 mg/L were found, respectively, the latter extrapolating the limit of 10 mg/L. It is noteworthy that the outliers (Figure 1a), considered atypical values, were included in the analysis. In a general manner, it was identified that no presence of nitrate was detected in 63 samples (39.9%), with greater absence in shallow springs (83.3% — 15/18), followed by headwaters (70.6% — 12/17), which reached a maximum concentration of 0.4 and 0.9 mg/L, respectively.

The results of this study corroborate previous research studies which point to the greater vulnerability of subterranean waters to contamination by nitrates, especially due to anthropic action linked to organic residues (Gan et al., 2022; Soleimani et al., 2022). In contrast, surface waters present smaller concentrations (Alaburda and Nishihara, 1998; Ministério das Cidades, 2009), suggesting shorter exposure, but not being exempt from risk, mainly in areas with intensive agricultural activity (Yang et al., 2022). The analysis of sources in WSS and ISS shows better quality in the WSSs regarding nitrate levels (Figures 1b and 1c), indicating that they are, in general, safer.

These findings emphasize the importance of understanding the processes that influence the dynamics of nitrogen, especially in rural areas. In this context, leaching presents itself as an essential component, even though it is frequently neglected due to the difficulty involved in its quantification and to its discrete nature. Nonetheless, this process may generate significant impacts, contributing to the contamination of surface water bodies and, especially, subterranean waters (Dahan et al., 2014).

Presence of nitrate in rural communities' waters

The communities covered by the 16 WSS, *quilombola* and riparian, include a total of 624 families (Table 3), while the ISSs total 142 families. It is possible to observe that the nitrate concentration in waters of collective systems (WSS) varied from "undetected" to 1.80 mg/L, with an average of 0.35 mg/L and a median of 0.05 mg/L.

The families supplied by ISS waters are exposed to greater nitrate concentrations (Figure 2), especially subterranean waters (Figure 1a). It is noteworthy that, among the agrarian reform settlements studied, none is supplied by WSS, which puts that population in a more vulnerable condition to nitrate contamination. Furthermore, it is necessary to warn about the presence of atypical values (outliers) in waters of certain communities, such as Rochedo, São Lourenço, Landi, Sumidouro and Pelotas (Figure 2b), and the presence of specific contamination sources, which demand more thorough investigation. The outliers may distort the central tendency values (Valladares Neto et al., 2017), but cannot be discarded due to their importance in the analysis.

It was also observed that, in the communities of Povoado Moinho (1 sample of WSS) and Povoado Vermelho (1 WSS and 1 ISS samples), where the water consumed originates from headwaters, the presence of nitrate was not detected. On the other hand, in the remaining 22 evaluated communities, nitrate was identified in 95 out of the 155 remaining samples.

Table 2 – Minimum and maximum nitrate concentrations detected in the rural communities' supply sources, as well as the average and median values, variation coefficient and standard deviation.

Supply Source	Quantity of Samples	Nitrate Concentration (mg/L)				DP (mg/L)	CV (%)
		Min.	Max.	Avg	median		
Cistern (rainwater)	19	0.1	2.1	0.853	0.7	0.544	64
Surface Spring	16	0.0*	0.4	0.044	0.0	0.102	25
Headwater	17	0.0*	0.9	0.071	0.0	0.227	31
Excavated Deep Well	47	0.0*	9.7	1.436	0.4	2.358	16
Deep Tube Well	28	0.0*	4.5	0.629	0.1	1.197	18
Shallow Tube Well	31	0.0*	11.6	1.287	0.1	2.836	22
Overall Total	**158**						

*Samples where nitrate presence was not detected.

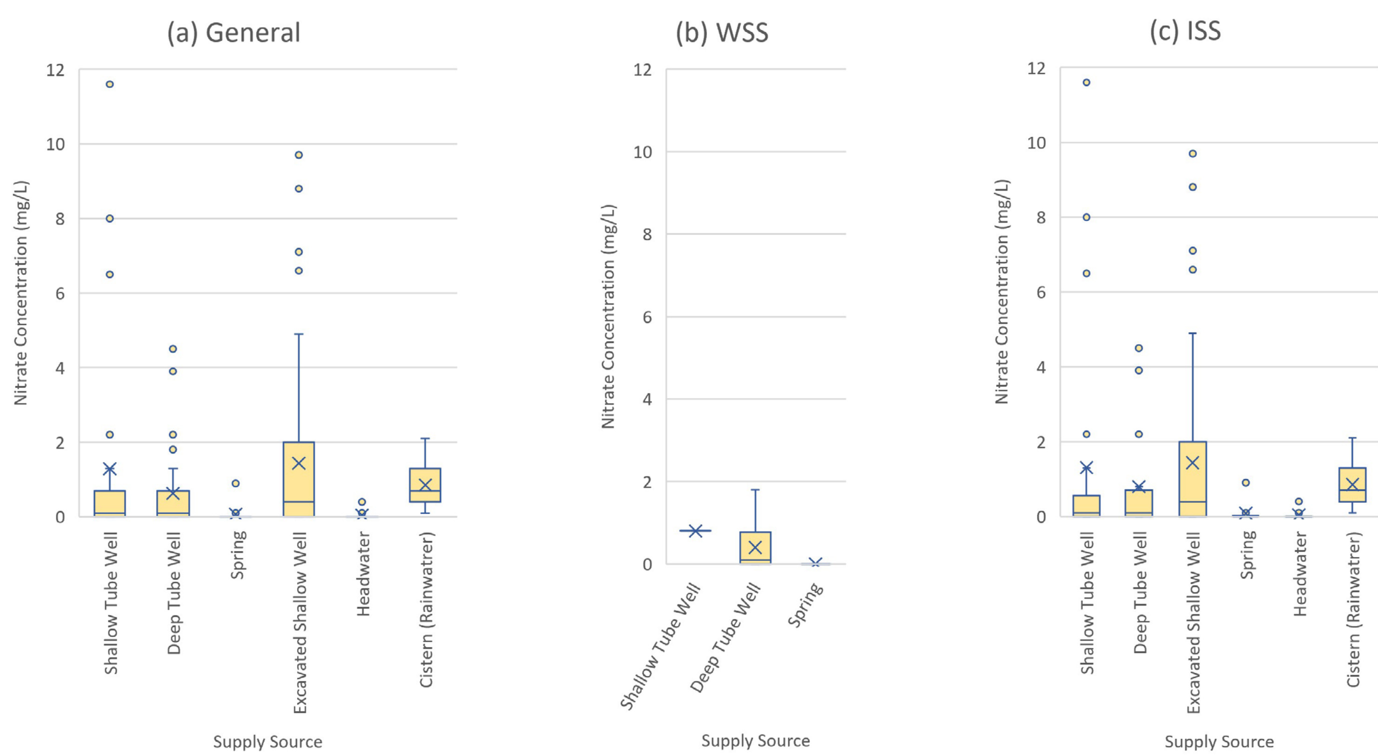

Figure 1 – (a) Concentration of nitrate detected in the water supply sources of rural communities, (b) covered by Water Supply Systems (WSS) or (c) by Individual Supply Solution (ISS).

Hazard quotient and hazard index

By water supply source

Table 4 presents the results obtained for HQ (adults, children and babies) and for HI, regarding the minimum, median and maximum nitrate concentrations detected for each water supply source.

The results of HQ and HI indicate that, in spite of all the water supply sources presenting average values below 1.0, there are sources which obtained values above the limit when considering the maximum concentration.

These findings are consistent with previous studies which used the HI or HQ to evaluate the risk of contamination in waters destined for

Table 3 – Nitrate concentration in waters distributed by the water supply systems and covered population.

Water supply source	Community WSS	Municipality	Number of families covered (inhab./house)	Nitrate (mg/L)
Deep tube well	Baco Pari (Q)	Posse	44 (4.5)	0.40
	Castelo Retiro Três Rios 1 (Q)	Simolândia	70 (2.5)	0.10
	Castelo Retiro Três Rios 2 (Q)			ND
	Castelo Retiro Três Rios 3 (Q)			0.20
	Castelo Retiro Três Rios 4 (Q)			ND
	Canabrava (Q)	Flores de Goiás	108 (3.0)	0.10
	Extrema (Q)	Iaciara	41 (2.7)	1.30
	Povoado Verissimo (R)	Goiandira	27 (2.5)	0.90
	Pouso Alegre de Goiás (Q)	Mineiros	8 (2.4)	0.10
	Vazante 1 (Q)	Divinópolis de Goiás	129 (2.9)	ND
	Vazante 2 (Q)			1.80
	São Domingos (Q)	Cavalcante	77 (3.4)	ND
Shallow tube well	Olhos d'Água (R)	Gameleira de Goiás	8 (3.0)	0.80
Headwater	Povoado Moinho (Q)	Alto Paraiso de Goiás	47 (3.6)	ND
	Forte (Q)	São João da Aliança	39 (2.3)	ND
	Povoado Vermelho (Q)	Niquelândia	26 (2.3)	ND
Total	**16 WSS**		**624 families (1,873 inhabitants)**	

ND: Undetected; Q: *quilombola* community; R: riparian community.

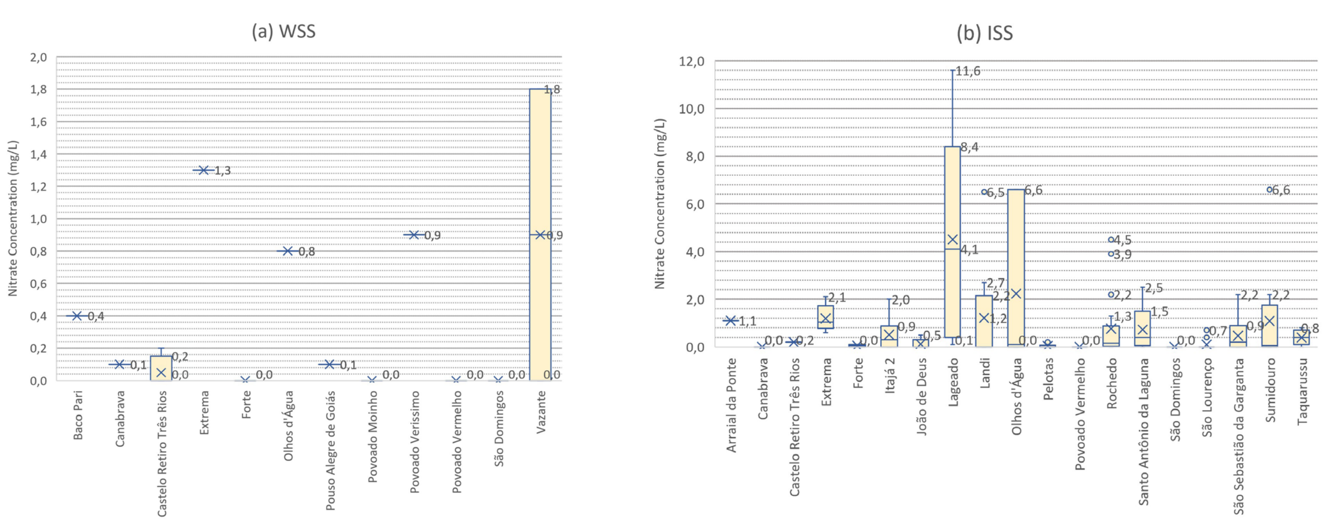

Figure 2 – Nitrate concentration detected in water supply sources of communities, presented by the means of supplying, which includes (a) water supply systems (WSS) and (b) individual supplying solution (ISS).

human consumption in rural areas (Meng et al., 2021; Zakaria et al., 2022), especially with regard to contamination by nitrate (Eggers et al., 2018; Qasemi et al., 2018; Zhang et al., 2021). It is important to highlight that, even if the HQ values for adults are below the 1.0 limit, chronic exposure to nitrates in moderate concentrations might have long-term cumulative effects, such as an increase in cardiovascular diseases and carcinogenic potential (Wang et al., 2022; Liu et al., 2023). Therefore, even in communities with low HQ values, it is necessary to implement preventive measures to reduce exposure to nitrates.

By community

The results for HQ for demographic groups: adults, children and babies, as well as HI regarding quality in terms of nitrate for different communities (Table 5), indicate a non-cancerous risk associated with the ingestion of nitrate through water. HQ and HI values for the communities of Povoado Moinho and Povoado Vermelho were not calculated, both of which are served by headwater, and no nitrate was detected.

The communities of Lageado, Olhos d'Água and Sumidouro presented the greatest HQ and HI values based on maximum nitrate concentrations, which was expected, considering the greatest levels observed in these locations. However, upon considering the concentrations' median, the highest HQ and HI values were verified in the communities of Arraial da Ponte, Extrema and Povoado Veríssimo. Even so, all the communities remained below the limits established by USEPA (2024) for this parameter.

Due to the greater susceptibility of children and babies, given their smaller body weight and greater water consumption by weight unit, these groups tend to present higher HQ values (Table 5 and Figure 3), as also observed in Sichuan, China (Zhang et al., 2021). Thus, there is a greater risk for this demographic group in communities with high nitrate concentration in the water. Even if they are the group most susceptible to the said risk, the HQ for children and babies did not surmount the 1.0 limit, differently from other studies found in the literature which did find such values (Qasemi et al., 2018; Karunanidhi et al., 2020; Rahman et al., 2021).

Table 4 – Results obtained for Hazard Quotient (adults, children and babies) and for Hazard Index, regarding the maximum, minimum and median nitrate concentrations detected in supply sources.

Supply Source	Maximum Concentration					
	Samples amount	Nitrate (mg/L)	HQ Adult	HQ Children	HQ Baby	HI
Cistern (rainwater)	19	2.1	0.105	0.158	0.168	0.431
Surface spring	16	0.4	0.020	0.030	0.032	0.082
Headwater	17	0.9	0.045	0.068	0.072	0.185
Excavated shallow well	47	9.7	0.485	0.728	0.776	1,989
Deep tube well (artesian)	28	4.5	0.225	0.338	0.360	0.923
Shallow tube well (mini-well)	31	11.6	0.580	0.870	0.928	2.378
Supply Source	**Maximum Concentration**					
	Samples amount	**Nitrate (mg/L)**	**HQ Adult**	**HQ Children**	**HQ Baby**	**HI**
Cistern (rainwater)	19	0.1	0.005	0.008	0.008	0.021
Surface spring	16	0.0	0.000	0.000	0.000	0.000
Headwater	17	0.0	0.000	0.000	0.000	0.000
Excavated shallow well	47	0.0	0.000	0.000	0.000	0.000
Deep tube well (artesian)	28	0.0	0.000	0.000	0.000	0.000
Shallow tube well (mini-well)	31	0.0	0.000	0.000	0.000	0.000
Supply Source	**Maximum Concentration**					
	Samples amount	**Nitrate (mg/L)**	**HQ Adult**	**HQ Children**	**HQ Baby**	**HI**
Cistern (rainwater)	19	0.7	0.035	0.053	0.056	0.144
Surface spring	16	0.0	0.000	0.000	0.000	0.000
Headwater	17	0.0	0.000	0.000	0.000	0.000
Excavated shallow well	47	0.4	0.020	0.030	0.032	0.082
Deep tube well (artesian)	28	0.1	0.005	0.008	0.008	0.021
Shallow tube well (mini-well)	31	0.1	0.005	0.008	0.008	0.021

Table 5 – Results of nitrate concentration, Hazard Index (HI) and Hazard Quotient (HQ) for each demographic group of the populations with the maximum, median and minimum concentration of nitrate of the rural communities.

Community	Maximum Concentration					Minimum Concentration					Median Concentration				
	Nitrate (mg/L)	HQ Adult	HQ Children	HQ Baby	HI	Nitrate (mg/L)	HQ Adult	HQ Children	HQ Baby	HI	Nitrate (mg/L)	HQ Adult	HQ Children	HQ Baby	HI
Arraial da Ponte*	1.100	0.055	0.083	0.088	0.226	1.100	0.055	0.083	0.088	0.226	1.100	0.055	0.083	0.088	0.226
Baco Pari*	0.400	0.020	0.030	0.032	0.082	0.400	0.020	0.030	0.032	0.082	0.400	0.020	0.030	0.032	0.082
Canabrava	0.100	0.005	0.008	0.008	0.021	0.100	0.005	0.008	0.008	0.021	0.100	0.005	0.008	0.008	0.021
Castelo Retiro Três Rios	0.200	0.010	0.015	0.016	0.041	0.200	0.010	0.015	0.016	0.041	0.200	0.010	0.015	0.016	0.041
Extrema	2.100	0.105	0.158	0.168	0.431	0.600	0.030	0.045	0.048	0.243	1.300	0.065	0.098	0.104	0.267
Forte	0.100	0.005	0.008	0.008	0.021	0.100	0.005	0.008	0.008	0.021	0.100	0.005	0.008	0.008	0.021
Itajá 2	2.000	0.100	0.150	0.160	0.410	0.200	0.010	0.015	0.016	0.185	0.400	0.020	0.030	0.032	0.082
João de Deus	0.500	0.025	0.038	0.040	0.103	0.100	0.005	0.008	0.008	0.053	0.300	0.015	0.023	0.024	0.062
Lageado	11.600	0.580	0.870	0.928	2.378	0.100	0.005	0.008	0.008	0.941	4.100	0.205	0.308	0.328	0.841
Landi	6.500	0.325	0.488	0.520	1.333	0.500	0.025	0.038	0.040	0.583	2.700	0.135	0.203	0.216	0.554
Olhos d'Água	6.600	0.330	0.495	0.528	1.353	0.100	0.005	0.008	0.008	0.541	0.800	0.040	0.060	0.064	0.164
Pelotas	0.200	0.010	0.015	0.016	0.041	0.100	0.005	0.008	0.008	0.029	0.150	0.008	0.011	0.012	0.031
Pouso Alegre de Goiás	0.100	0.005	0.008	0.008	0.021	0.100	0.005	0.008	0.008	0.021	0.100	0.005	0.008	0.008	0.021
Povoado Moinho	0.000	0.000	0.000	0.072	0.072	0.000	0.000	0.000	0.000	0.072	0.900	0.045	0.068	0.072	0.185
Povoado Verissimo*	0.900	0.045	0.068	0.360	0.473	0.900	0.045	0.068	0.072	0.473	0.100	0.005	0.008	0.008	0.021
Povoado Vermelho	0.000	0.000	0.000	0.200	0.200	0.000	0.000	0.000	0.000	0.200	0.100	0.005	0.008	0.008	0.021
Rochedo	4.500	0.225	0.338	0.056	0.619	0.100	0.005	0.008	0.008	0.069	0.200	0.010	0.015	0.016	0.041
Santa Fé da Laguna	2.500	0.125	0.188	0.176	0.489	0.100	0.005	0.008	0.008	0.189	0.800	0.040	0.060	0.064	0.164
São Domingos	0.000	0.000	0.000	0.528	0.528	0.000	0.000	0.000	0.000	0.528	0.400	0.020	0.030	0.032	0.082
São Lourenço	0.700	0.035	0.053	0.064	0.152	0.400	0.020	0.030	0.032	0.114	1.300	0.065	0.098	0.104	0.267
São Sebastião da Garganta	2.200	0.110	0.165	0.144	0.419	0.100	0.005	0.008	0.008	0.157	0.400	0.020	0.030	0.032	0.082
Sumidouro	6.600	0.330	0.495	0.000	0.825	0.100	0.005	0.008	0.008	0.013	0.100	0.005	0.008	0.008	0.021
Taquarussu	0.800	0.040	0.060	0.000	0.100	0.100	0.005	0.008	0.008	0.013	0.100	0.005	0.008	0.008	0.021
Vazante	1.800	0.090	0.135	0.000	0.225	1.800	0.090	0.135	0.144	0.225	0.900	0.045	0.068	0.072	0.185

*Community that possesses only one water sample.

Upon analyzing the HI values for each demographic group, based on the maximum, minimum and median concentrations (Figure 3), it is possible to observe that all the values remained below the 1.0 limit while considered separately, per group. In relation to the minimum concentration, most communities (58.3%) obtained values close to 0.01, due to the nitrate minimum concentrations staying close to 0.10 mg/L (Table 5).

On the other hand, discrepancies between the communities became more evident upon analyzing the HQ values for maximum concentrations, since the difference between them is greater. While in most communities (16) it was possible to observe a maximum concentration inferior to 2.50 mg/L, four communities showed a value above 6.0 mg/L, which makes them stand out with regard to HQ (Table 5). It can be noted through Figure 3 that the Lageado community presents the most critical value for the baby age group for maximum and median concentrations: $HQ_{maximum}$=0.93 and HQ_{median}=0.33. These communities with a HQ close to 1.0 are in need, therefore, of receiving more attention and being prioritized for interventions aimed at reducing nitrate concentration in the water consumed by the population.

Regarding the Hazard Index (Figure 4), it is noted that, of the five communities with greatest HI (HI>0.5) for the maximum concentration, two are riparian (Landi, Olhos d'Água), two are settlements (Lageado and Rochedo) and one is a *quilombola* community (Sumidouro), the most critical point having being found in Lageado (HI=2.38). It was observed that wells are the main supply sources in the communities with the worst results, Lageado being predominantly covered by excavated shallow wells (11 out of 13 samples), and Olhos d'Água having all samples from shallow tube wells. Such results corroborates those obtained in other studies, in which waters stemming from subterranean sources presented more critical HQ and HI results (Rahman et al., 2021; Gan et al., 2022; Soleimani et al., 2022).

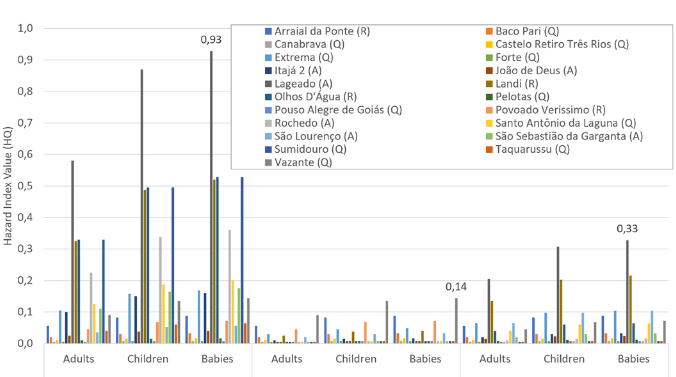

Figure 3 – Hazard Quotient (HQ) values for each age range, according to maximum, minimum and median concentrations.
Q: *quilombola* community; R: riparian community; A: agrarian reform settlement.

Contamination sources

It is noted that, in the majority of the studied communities (70.8%), the effluents are predominantly destined towards rudimentary cesspits (Table 6); moreover, in 50% of the communities there is waste disposal on land or water bodies. This scenario was observed in the five communities with the worst HI results (≥0.92): Lageado, Landi, Olhos d'Água, Sumidouro and Rochedo, all having ISS. The results are consistent with a study in which a correlation is established between the use of rudimentary cesspits and the occurrence of diarrheal diseases (Visser et al., 2011). The presence of rudimentary cesspits, due to them usually not being properly waterproofed, allows the infiltration of organic residues in the soil, which may contaminate the subterranean aquifers. Besides increasing the possibility of water contamination, the rudimentary cesspits are more prone to present problems, such as crumbling walls, rainwater overflows or leakages (Figueiredo et al., 2019).

The issue that the rudimentary cesspit may cause to water quality may be aggravated where the distance between water collection and the cesspit is inferior to 45 meters. Thus, situations of such nature have been found in 29.2% of the communities (7/24), which increases the risk of cross-contamination. These results are consistent with studies which found out that rudimentary cesspits are a significant form of contamination in rural areas (Figueiredo et al., 2019; Do Carmo Filho et al., 2021).

Another potential contamination source is the presence of animal excreta in the yard, close to the WSSs. This condition was detected in house yards in 16 communities (Table 6) among those in worse situation for the presence of nitrate and HI, which demonstrates the need

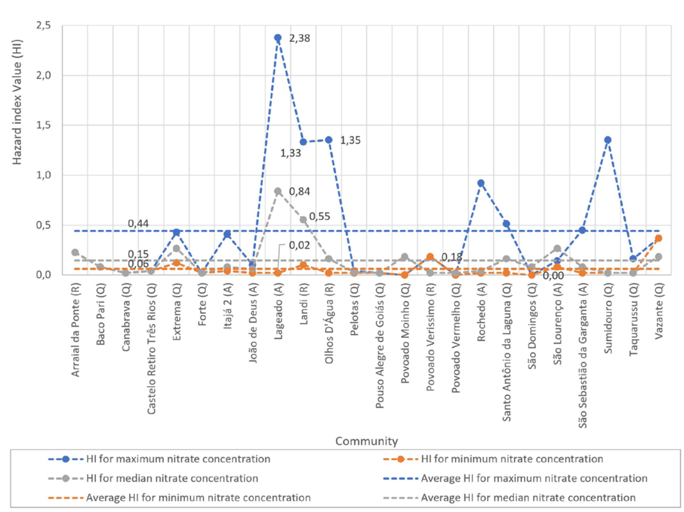

Figure 4 – Hazard Index (HI) determined for the minimum, maximum and median nitrate concentration in the waters of the researched communities.
Q: *quilombola* communities; R: riparian communities; A: agrarian reform settlement.

for greater care with this potential contaminant. Lack of proper handling of said residues may result in soil contamination and/or leaching of nitrates to surface and subterranean water bodies (Dahan et al., 2014), representing an additional risk to the health of the people living in these locations.

The results of this study are consistent with previous research that evaluated nitrate contamination in rural areas. For example, in Kenya, the subterranean water contamination by nitrate was propelled by an inadequate sewer system structure and application of animal manure of agriculture or free-range cattle farming (Nyilitya et al., 2020). It is reported that nitrate concentrations above 5 mg/L are associated with a 47% increase in the risk of spontaneous premature birth (Sherris et al., 2021; Ebdrup et al., 2022). These findings reinforce the need to establish more rigorous limits for nitrate concentration in potable water, especially in rural communities where contamination sources are more prevalent.

In contrast, some studies (Qasemi et al., 2018; Rahman et al., 2021; Soleimani et al., 2022) have reported even higher nitrate concentrations in intensive agricultural areas, where excessive use of nitrogen fertilizers is common. However, in the context of this study, the concentrations observed, albeit worrisome, do not reach the extreme levels reported in other regions, which suggests that the agricultural practices in the communities analyzed might be less intense.

The results of this study highlight the need to implement risk management measures in the analyzed rural communities. However, first and foremost, it is fundamental to improve the basic sanitation infrastructure, especially regarding the disposal of excreta and organic residues. The construction of adequate sceptic tanks and the implementation of sewer treatment systems may significantly reduce nitrate contamination (Visser et al., 2011).

Furthermore, it is necessary to promote sustainable agricultural practices that minimize the use of nitrogen fertilizers and encourage

Table 6 – Effluent destinations, presence of animal excreta and distance between water collection and rudimentary cesspits in the analyzed rural communities.

Community	Rudimentary Cesspits (%)	Sceptic tank (%)	Untreated, soil or water bodies disposal (%)	Presence of animal excreta in the yard	Distance between water collection and rudimentary cesspits inferior to 45 m
Arraial da Ponte	100.0	ND	ND	ND	ND
Baco Pari	50.0	3.8	46.2	ND	ND
Canabrava	95.2	ND	4.8	Sim	ND
Castelo Retiro Três Rios	82.9	5.7	11.4	ND	ND
Extrema	95.8	4.2	ND	Yes	ND
Forte	95.7	ND	4.3	Yes	ND
Itajá 2	64.7	29.4	5.9	Yes	ND
João de Deus	90.9	ND	9.1	Yes	Yes
Lageado	93.3	6.7	ND	Yes	Yes
Landi	100.0	ND	ND	Yes	Yes
Olhos d'Água	100.0	ND	ND	Yes	Yes
Pelotas	35.0	ND	65.0	Yes	ND
Pouso Alegre de Goiás	100.0	ND	ND	ND	ND
Povoado Moinho	82.1	14.3	3.6	ND	ND
Povoado Verissimo	94.7	5.3	ND	ND	ND
Povoado Vermelho	65.0	25.0	10.0	Yes	ND
Rochedo	100.0	ND	ND	Yes	Yes
Santa Fé da Laguna	82.9	5.7	11.4	Yes	Yes
São Domingos	55.6	5.6	38.8	ND	ND
São Lourenço	94.7	ND	5.3	Yes	ND
São Sebastião da Garganta	100.0	ND	ND	Yes	Yes
Sumidouro	92.4	3.8	3.8	Yes	ND
Taquarussu	73.7	ND	26.3	Yes	ND
Vazante	72.9	25.0	2.1	ND	ND

ND: non-detected.

crop rotation, as well as the use of organic manure. These measures may not only reduce water contamination, but also improve soil quality and agricultural productivity in the long term.

Conclusion

The present research allowed us to conclude that:

- Families that use water from excavated or tube shallow wells are more susceptible to nitrate contamination;
- ISSs, especially from underwater springs, are more prone to water contamination by nitrate;
- Surface springs and headwaters are the WSSs with the lowest nitrate concentrations;
- The families covered by WSS are exposed to waters with nitrate concentrations below the limit that is harmful to their health;
- The families living in agrarian reform settlements, by having ISSs only, are more prone to consuming water with nitrate;
- The presence of rudimentary cesspits close to the WSS enhances contamination by nitrate.

Lastly, continuous monitoring of water quality in the rural communities is recommended, especially in those with HI values above 1.0. The implementation of preemptive alert systems and education of the population concerning the risks associated with nitrate contamination are key strategies to protect the rural communities' health.

Author's contributions: **Ramos,** A.C.B.: conceptualization; data curation; formal analysis; funding; acquisition; investigation; methodology; writing – first draft; **Scalize**, P.S.: funding acquisition; supervision; validation; writing – first draft.

Conflicts of interest: the authors declare no conflicts of interest.

Funding: SanRural Project—Environmental Sanitation and Health in Rural and Traditional Communities of Goiás, Coordination for the Improvement of Higher Education Personnel(CAPES)-National Council for Scientific and Technological Development (CNPq).

References

Abdipour, H.; Azari, A.; Kamani, H.; Pirasteh, K.; Mostafapour, F.K.; Rayegnnakhost, S., 2025. Human health risk assessment for fluoride and nitrate contamination in drinking water of municipal and rural areas of Zahedan, Iran. Applied Water Science, v. 15, (47). https://doi.org/10.1007/s13201-025-02375-8.

Alaburda, J.; Nishihara, L., 1998. The occurrence of nitrogen compounds in well water. Revista de Saúde Pública, v. 32, (2), 160-165. https://doi.org/10.1590/S0034-89101998000200009.

Alfarisy, F.K.; Andriyani, I.; Bowo, C., 2020. Evaluation of water quality due to the use of intensive fertilizer on farmer level in the upstream of Bedadung Jember Watershed, East Java, Indonesia. Journal of Degraded and Mining Lands Management, v. 7, (4), 2301-2312. https://doi.org/10.15243/jdmlm.2020.074.2301.

American Public Health Association (APHA); American Water Works Association (AWWA); Water Environment Federation (WEF), 2022. Standard Methods for the Examination of Water and Wastewater. 24th ed. American Water Works Association, Water Environmental Federation, Washington, D.C.

Assis, E.M.D.; Santos, E.M.; Faria, M.C.D.S.; Rodrigues, J.L.; Garcez, A.; Bomfeti, C.A.; Barcellos, N.T., 2022. The vulnerability of indigenous populations: water quality consumed by the Maxakali community, Minas Gerais, Brazil. Sociedade & Natureza, v. 32, 265-275. https://doi.org/10.14393/SN-v32-2020-43436.

Bijay-Singh; Craswell, E., 2021. Fertilizers and nitrate pollution of surface and ground water: an increasingly pervasive global problem. Springer Nature Applied Sciences, v. 3, 518-541. https://doi.org/10.1007/s42452-021-04521-8.

Braga, D.L.; Bezerra, N.R.; Scalize, P.S., 2022. Proposition and application of an environmental salubrity index in rural agglomerations. Revista de Saúde Pública, v. 56, 44-59. https://doi.org/10.11606/s1518-8787.2022056003548.

Braimah, J.A.; Yirenya-Tawiah, D.R.; Gordon, C., 2021. Hand-dug well water quality: the case of two peri-urban communities in Ghana. West African Journal of Applied Ecology, v. 29, (1), 24-34.

Brasil, 2019. Programa Nacional de Saneamento Rural. Funasa, Ministério da Saúde, Brasília, 260 p.

Brasil, 2021. Portaria GM/MS Nº 888, de 4 de maio de 2021. Altera o Anexo XX da Portaria de Consolidação GM/MS nº 5, de 28 de setembro de 2017, para dispor sobre os procedimentos de controle e de vigilância da qualidade da água para consumo humano e seu padrão de potabilidade. Diário Oficial da União (Accessed Aug. 2024) at:. https://www.in.gov.br/en/web/dou/-/portaria-gm/ms-n-888-de-4-de-maio-de-2021-318461562.

Campbell, T.A.; Masarik, K.C.; Heineman, E.M.; Kucharik, C.J., 2023. Quantifying the spatiotemporal variability of nitrate in irrigation water across the Wisconsin Central Sands, Journal of Environmental Quality, v. 52, (6), 1102-1114. https://doi.org/10.1002/jeq2.20521.

Dahan, O.; Babad, A.; Lazarovitch, N.; Russak, E.E.; Kurtzman, D., 2014. Nitrate leaching from intensive organic farms to groundwater. Hydrology and Earth System Sciences, v. 18, (1), 333-341. https://doi.org/10.5194/hess-18-333-2014.

Do Carmo Filho, O.J.S.; Albuquerque, A.R.; Oliveira, J.C.C., 2021. Urban River Basins: The precariousness reflection of sanitation in Manaus, Amazonas – Brazil. Ateliê Geográfico, 15, (2), 70-93. https://doi.org/10.5216/ag.v15i2.64877.

Ebdrup, N.H.; Schullehner, J.; Knudsen, U.B.; Liew, Z.; Thomsen, A.M.L.; Lyngso, J.; Bay, B.; Arendt, L.H.; Clemmensen, P.J.; Sigsgaad, T.; Hansen, B.; Ramlau-Hansen, C.H., 2022. Drinking water nitrate and risk of pregnancy loss: a nationwide cohort study. Environmental Health, v. 21, (1), 87-99. https://doi.org/10.1186/s12940-022-00897-1.

Eggers, M.J.; Doyle, J.T.; Lefthand, M.J.; Young, S.L.; Moore-Nall, A.L.; Kindness, L.; Medicine, R.O.; Ford, T.E.; Dietrich, E.; Parker, A.E.; Hoover J.H.; Camper, A.K., 2018. Community engaged cumulative risk assessment of exposure to inorganic well water contaminants, crow reservation, Montana. International Journal of Environmental Research and Public Health, v. 15, (1), 76-109. https://doi.org/10.3390/ijerph15010076.

Figueiredo, I.C.S.; Miyazaki, C.K.; Madrid, F.J.P.L.; Duarte, N.C.; Magalhães, T.M.; Tonetti, A.L., 2019. Cesspool pit in rural sanitation: appropriate solution or precarious alternative? Revista DAE, v. 67, (220), 87-99. https://doi.org/10.4322/dae.2019.057.

Freitas, M.B.; Brilhante, O.M.; Almeida, L.M., 2001. The importance of water testing for public health in two regions in Rio de Janeiro: a focus on fecal coliforms, nitrates, and aluminum. Cadernos de Saúde Pública, v. 17, (3), 651-660. https://doi.org/10.1590/S0102-311X2001000300019.

Galezzo, M.A.; Rodríguez Susa, M., 2021. The challenges of monitoring and controlling drinking-water quality in dispersed rural areas: a case study based on two settlements in the Colombian Caribbean. Environmental Monitoring Assessment, v. 193, 373. https://doi.org/10.1007/s10661-021-09138-3.

Gan, L.; Huang, G.; Pei, L.; Gan, Y.; Liu, C.; Yang, M.; Hang, D.; Song, J., 2022. Distributions, origins, and health-risk assessment of nitrate in groundwater in typical alluvial-pluvial fans, North China Plain. Environmental Science and Pollution Research, v. 29, (12), 17031-17048. https://doi.org/10.1007/s11356-021-17067-4.

García-Ávila, F.; Guanoquiza-Suárez, M.; Guzmán-Galarza, J.; Cabello-Torres, R.; Valdiviezo-Gonzales, L., 2023. Rainwater harvesting and storage systems for domestic supply: An overview of research for water scarcity management in rural areas. Results in Engineering, v. 18, 101153. https://doi.org/10.1016/j.rineng.2023.101153.

Islam, A.R.M.T.; Kabir, M.M.; Faruk, S.; Al Jahin, J.; Bodrud-Doza, M.; Didar-Ul-Alam, M.; Bahadur, N.M.; Mohinuzzaman, M.; Fatema, K.J.; Rahman, M.S.; Choudhury, T.R., 2021. Sustainable groundwater quality in southeast coastal Bangladesh: co-dispersions, sources, and probabilistic health risk assessment. Environment, Development and Sustainability, v. 23, 18394-18423. https://doi.org/10.1007/s10668-021-01447-4.

Karunanidhi, D.; Aravinthasamy, P.; Roy, P.D.; Praveenkumar, R.M.; Prasanth, K.; Selvapraveen, S.; Thowbeekrahman, A.; Subramani, T.; Srinivasamoorthy, K., 2020. Evaluation of non-carcinogenic risks due to fluoride and nitrate contaminations in a groundwater of an urban part (Coimbatore region) of south India. Environmental Monitoring and Assessment, v. 192, 102-117. https://doi.org/10.1007/s10661-019-8059-y.

Liu, H.; Huang, Y.; Huang, M.; Wang, M., Ming, Y.; Chen, W.; Jia, B., 2023. From nitrate to NO: potential effects of nitrate-reducing bacteria on systemic health and disease. European Journal Medical Research, v. 28, 425-448. https://doi.org/10.1186/s40001-023-01413-y.

Lopes, H.T.L.; Baumann, L.R.F.; Scalize, P.S., 2023. A contamination predictive model for *Escherichia coli* in rural communities dug shallow wells. Sustainability, v. 15, (3), 2408-2423. https://doi.org/10.3390/su15032408.

Meng, T.; Cheng, W.; Wan, T.; Wang, M.; Ren, J.; Li, Y.; Huang, C., 2021. Occurrence of antibiotics in rural drinking water and related human health risk assessment. Environmental Technology, v. 42, (5), 671-681. https://doi.org/10.1080/09593330.2019.1642390.

Ministério das Cidades, 2009. Transversal: saneamento básico integrado às comunidades rurais e populações Tradicionais: guia do profissional em treinamento - Nível 2. Ministério das Cidades, Brasília, 88 p. (Accessed Dec 1, 2024) at:. https://boletimdosaneamento.com.br/wp-content/uploads/2023/08/SanBasIntegradoComunRurais-ePopTradicionais_ReCESA.pdf.

Nyilitya, B.; Mureithi, S.; Boeckx, P., 2020. Tracking sources and fate of groundwater nitrate in Kisumu City and Kano Plains, Kenya. Water, v. 12, (2), 401. https://doi.org/10.3390/w12020401.

Oliveira, R.M., 2023. Nitrato nas águas subterrâneas de fortaleza: ocorrências, causas e riscos a saúde da população. Doctoral Thesis in Geology, Universidade Federal do Ceará, Fortaleza (Accessed Aug 10, 2024) at:. https://repositorio.ufc.br/bitstream/riufc/72359/7/2023_tese_rmoliveira.pdf.

Organização das Nações Unidas (ONU), 2019. Os Objetivos de Desenvolvimento Sustentável no Brasil. ONU (Accessed May 19, 2024) at:. https://nacoesunidas.org/

Pimentel-Gomes, F., 1987. Curso de estatística experimental. 12. ed. Nobel, São Paulo, 466 p.

Pinheiro, A.G.R.S.C., 2023. Padrões alimentares vegetarianos em idade pediátrica relacionados com a exposição a nitratos e nitritos. Doctoral Thesis (Accessed May 19, 2024) at:. https://www.proquest.com/openview/df6c238936d61e64bdeb9bb0442cd56d/1?cbl=2026366&diss=y&pq-origsite=gscholar.

Prickett, M.; Chambers, T.; Hales, S. 2023. When the first barrier fails: public health and policy implications of nitrate contamination of a municipal drinking water source in Aotearoa New Zealand. Australasian Journal of Water Resources, v. 28, (1), 64-73. https://doi.org/10.1080/13241583.2023.2272324.

Projeto SanRural, 2021-2022. Projeto Saneamento e Saúde Ambiental em Comunidades Rurais e Tradicionais de Goiás, 115 v. Coleção Diagnóstico Técnico Participativo (Accessed Apr 26, 2025) at:. https://sanrural.ufg.br/blog/2022/03/16/6094/.

Qasemi, M.; Farhang, M.; Biglari, H.; Afsharnia, M.; Ojrati, A.; Khani, F.; Samiee, M.; Zarei, A., 2018. Health risk assessments due to nitrate levels in drinking water in villages of Azadshahr, northeastern Iran. Environmental Earth Sciences, v. 77, 782. https://doi.org/10.1007/s12665-018-7973-6.

Rahman, Z.U.; Ahmad, S.; Fidel, R.; Khalid, S.; Ahmad, I.; Humphrey, O.S.; Khan, H.; Khan, B., 2021. Faecal and nitrate contamination in the groundwater of Mardan district, Pakistan. Environmental Geochemistry and Health, v. 43, 3615-3624. https://doi.org/10.1007/s10653-021-00848-8.

Rezende, C.R.; Campos, J.C.V.; Melo, V.S.R.; Machado, C.S.; Santos Senhuk, A.P.M.; Ferreira, D.C., 2023. Groundwater quality in the Uberaba-MG urban area: health risk assessment. Scientia Plena, v. 19, (2), 24301-24312. https://doi.org/10.14808/sci.plena.2023.024301.

Rodrigues, A.; Macedo, M.N.; Silvério, D.V.; Maracahipes, L.; Coe, M.T.; Breo, P.M.; Shimbo, J.Z.; Rajão, R.; Soares Filho, B.; Bustamante, M.M.C., 2022. Cerrado deforestation threatens regional climate e water availability for agriculture e ecosystems, Global Change Biology, v. 28, (22), 6807-6822. https://doi.org/10.1111/gcb.16386.

Rukavishnikov, V.S.; Efimova, N.V.; Savchenkov, M.F.; Mylnikova, I.V.; Lisovtsov, A.A. 2024. Quality of drinking water and risk to the health of the population of the south Baikal region (Russia), Emerging Contaminants, v. 10, (2), 100300. https://doi.org/10.1016/j.emcon.2024.100300.

Santos, M.V.A.; Fuentes, T.G.Q.; Melo, D.C.; Chiarelotto, M., 2023. Evaluation of water quality and management of domestic cisterns in rural community of western Bahia (Brazil). Revista Brasileira de Meio Ambiente, v. 11, (1), 132-150. https://doi.org/10.5281/zenodo.8023320.

Scalize, P.S.; Barros, E.F.S.; Soares, L.A.; Hora, K.E.R.; Ferreira, N.C.; Baumann, L.R.F., 2014. Avaliação da qualidade da água para abastecimento no assentamento de reforma agrária Canudos, Estado de Goiás. Revista Ambiente & Água, v. 9, (4), 696-707. https://doi.org/10.4136/ambi-agua.1386.

Scalize, P.S.; Bezerra, N.R.; Baracho, R.O., 2022. Safety index of individual basic sanitation systems in rural area. Electronic Journal Environmental

Forum of Alta Paulista, v. 18, (3), 56-75. https://doi.org/10.17271/1980082718320223302.

Scalize, P.S.; Gabriel, E.F.M.; Lima, F.S.; Arruda, P.N.; Lopes, H.T.L.; Reis, Y.P.; Carneiro, L.C.; Bezerra, N.R.; Fiaccadori, F.S.; Baumann, L.R.F., 2021. Physicochemical, microbiological quality, and risk assessment of water consumed by a quilombola community in midwestern Brazil. Environmental Science and Pollution Research, v. 28, 35941-35957. https://doi.org/10.1007/s11356-021-13146-8.

Sherris, A.R.; Baiocchi, M.; Fendorf, S.; Luby, S.P.; Yang, W.; Shaw, G.M., 2021. Nitrate in drinking water during pregnancy and spontaneous preterm birth: a retrospective within-mother analysis in California. Environmental Health Perspectives, v. 129, (5), 057001. https://doi.org/10.1289/ehp8205.

Silveira, P.; Rebelo, M.T.; Salvador, D., 2024. Challenges of providing safe drinking water in African rural communities: a case study on the Oio Region, Guinea-Bissau. Water, v. 16, (24), 3621. https://doi.org/10.3390/w16243621.

Soleimani, H.; Nasri, O.; Ghoochani, M.; Azhdarpoor, A.; Dehghani, M.; Radfard, M.; Darvishmotevalli, M.; Oskoei, V.; Heydari, M., 2022. Groundwater quality evaluation and risk assessment of nitrate using monte carlo simulation and sensitivity analysis in rural areas of Divandarreh County, Kurdistan province, Iran. International Journal of Environmental Analytical Chemistry, v. 102, (10), 2213-2231. https://doi.org/10.1080/03067319.2020.1751147.

Stokdyk, J.; Firnstahl, A.; Bradbury, K.; Muldoon, M.; Kieke, B.; Borchardt, M.A., 2025. Sources and risk factors for nitrate, pathogens, and fecal contamination of private wells in rural southwestern Wisconsin, USA. Water Research, v. 275, 123202. https://doi.org/10.1016/j.watres.2025.123202.

United States Environmental Protection Agency (USEPA), 1989. Risk Assessment Guidance for Superfund (RAGS), Volume I: Human Health Evaluation Manual (HHEM). Part A. Baseline risk assessment. Interim Final. USEPA, Office of Emergency and Remedial Response, Washington, D.C. (EPA/540/1-89/002) (Accessed Dec 1, 2024) at:. https://www.epa.gov/sites/default/files/2015-09/documents/rags_a.pdf.

United States Environmental Protection Agency (USEPA), 2024. National Primary Drinking Water Regulations. USEPA, Washington, D.C. (Accessed Dec 1, 2024) at:. https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations.

Valladares Neto, J.; Santos, C.B., Torres, E.M.; Estrela, C., 2017. Boxplot: um recurso gráfico para a análise e interpretação de dados quantitativos. Revista Odontológica do Brasil Central, v. 26, (76), 1-6. https://doi.org/10.36065/robrac.v26i76.1132.

Visser, S.; Giatti, L.L.; Carvalho, R.A.C.D.; Guerreiro, J.C.H., 2011. Study of the association between socio-environmental factors and the prevalence of intestinal parasitosis in the suburbs of the city of Manaus in the state of Amazonas, Brazil. Ciência & Saúde Coletiva, v. 16, (8), 3481-3492. https://doi.org/10.1590/s1413-81232011000900016

Wang, L.; Fu, Z.; Zheng, J.; Wang, S.; Ping, Y.; Gao, B.; Mo, X.; Huang, J., 2022. Exposure to perchlorate, nitrate and thiocyanate was associated with the prevalence of cardiovascular diseases. Ecotoxicology and Environmental Safety, v. 230, 113161. https://doi.org/10.1016/j.ecoenv.2022.113161.

Yang, J.; Liu, Y.; Tan, X.; Xu, C.; Lin, A., 2022. Safety assessment of drinking water sources along Yangtze River using vulnerability and risk analysis. Environmental Science and Pollution Research, v. 29, (18), 27294-27310. https://doi.org/10.1007/s11356-021-18297-2.

Zakaria, N.; Gibrilla, A.; Owusu-Nimo, F.; Adomako, D.; Anornu, G., 2022. Occurrence, spatial distribution, and health risk assessment of heavy metals in groundwater from parts of the Kassena Nankana area, Ghana. Sustainable Water Resources Management, v. 8, (3), 77. https://doi.org/10.1007/s40899-022-00658-5.

Zhang, Y.; He, Z.; Tian, H.; Huang, X.; Zhang, Z.; Liu, Y.; Li, R., 2021. Hydrochemistry appraisal, quality assessment and health risk evaluation of shallow groundwater in the Mianyang area of Sichuan Basin, southwestern China. Environmental Earth Sciences, v. 80, (17), 576. https://doi.org/10.1007/s12665-021-09894-y.

Appendix 1 – Nitrate concentrations by community, supply system and consumption source.

Municipality	Rural Community	Community Typology	Water Supply Source	Supply System	Nitrate Concentration in Water (mg/L)
Iaciara	Extrema	Quilombola	Cistern (rainwater)	ISS	1.30
Iaciara	Extrema	Quilombola	Cistern (rainwater)	ISS	0.80
Silvânia	São Sebastião da Garganta	Settlement	Spring	ISS	0.00
Iaciara	Extrema	Quilombola	Cistern (rainwater)	ISS	0.80
Campos Belos	Taquarussu	Quilombola	Spring	ISS	0.00
Monte Alegre de Goiás	Pelotas	Quilombola	Spring	ISS	0.00
Iaciara	Extrema	Quilombola	Cistern (rainwater)	ISS	0.60
Monte Alegre de Goiás	Pelotas	Quilombola	Spring	ISS	0.00
Iaciara	Extrema	Quilombola	Cistern (rainwater)	ISS	0.80
Monte Alegre de Goiás	Pelotas	Quilombola	Spring	ISS	0.00
Iaciara	Extrema	Quilombola	Cistern (rainwater)	ISS	1.70
Iaciara	Extrema	Quilombola	Cistern (rainwater)	ISS	0.70
Iaciara	Extrema	Quilombola	Cistern (rainwater)	ISS	1.30
Iaciara	Extrema	Quilombola	Cistern (rainwater)	ISS	2.10
Iaciara	Extrema	Quilombola	Cistern (rainwater)	ISS	1.80
Monte Alegre de Goiás	Pelotas	Quilombola	Spring	ISS	0.00
Monte Alegre de Goiás	Pelotas	Quilombola	Spring	ISS	0.00
Campos Belos	Taquarussu	Quilombola	Cistern (rainwater)	ISS	0.80
Campos Belos	Taquarussu	Quilombola	Cistern (rainwater)	ISS	0.70
Campos Belos	Taquarussu	Quilombola	Cistern (rainwater)	ISS	0.40
Goianésia	Itajá 2	Settlement	Spring	ISS	0.00
Goianésia	Itajá 2	Settlement	Spring	ISS	0.00
Professor Jamil	Rochedo	Settlement	Surface Spring	ISS	0.00
Campos Belos	Taquarussu	Quilombola	Cistern (rainwater)	ISS	0.40
Campos Belos	Taquarussu	Quilombola	Cistern (rainwater)	ISS	0.50
Campos Belos	Taquarussu	Quilombola	Cistern (rainwater)	ISS	0.30
Campos Belos	Taquarussu	Quilombola	Cistern (rainwater)	ISS	0.40
Campos Belos	Taquarussu	Quilombola	Cistern (rainwater)	ISS	0.70
Campos Belos	Taquarussu	Quilombola	Cistern (rainwater)	ISS	0.10
Monte Alegre de Goiás	Pelotas	Quilombola	Surface Spring	ISS	0.20
Professor Jamil	Rochedo	Settlement	Surface Spring	ISS	0.10
Padre Bernardo	Sumidouro	Quilombola	Surface Spring	ISS	0.40
Silvânia	São Sebastião da Garganta	Settlement	Headwater	ISS	0.90
Simolândia	Castelo Retiro Três Rios	Quilombola	Headwater	ISS	0.20
São João da Aliança	Forte	Quilombola	Headwater	ISS	0.10
Padre Bernardo	Sumidouro	Quilombola	Surface Spring	ISS	0.00
Goianesia	Itajá 2	Settlement	Excavated shallow tube	ISS	2.00
Goianesia	Itajá 2	Settlement	Excavated shallow tube	ISS	1.10
Goianesia	Itajá 2	Settlement	Excavated shallow tube	ISS	0.80

It continues...

Appendix 1 – Continuation.

Municipality	Rural Community	Community Typology	Water Supply Source	Supply System	Nitrate Concentration in Water (mg/L)
Goianesia	Itajá 2	Settlement	Excavated shallow tube	ISS	0.30
Goianesia	Itajá 2	Settlement	Excavated shallow tube	ISS	0.40
Goianesia	Itajá 2	Settlement	Excavated shallow tube	ISS	0.20
São Miguel do Araguaia	Lageado	Settlement	Excavated shallow tube	ISS	0.50
São Miguel do Araguaia	Lageado	Settlement	Excavated shallow tube	ISS	7.10
São Miguel do Araguaia	Lageado	Settlement	Excavated shallow tube	ISS	0.10
Padre Bernardo	Sumidouro	Quilombola	Surface Spring	ISS	0.00
Padre Bernardo	Sumidouro	Quilombola	Surface Spring	ISS	0.00
São Miguel do Araguaia	Lageado	Settlement	Excavated shallow tube	ISS	0.40
Silvânia	São Sebastião da Garganta	Settlement	Headwater	ISS	0.00
Cavalcante	São Domingos	Quilombola	Headwater	ISS	0.00
Alto Paraiso de Goiás	Povoado Moinho	Quilombola	Headwater	WSS	0.00
São João da Aliança	Forte	Quilombola	Headwater	ISS	0.00
São Miguel do Araguaia	Lageado	Settlement	Excavated shallow tube	ISS	9.70
São João da Aliança	Forte	Quilombola	Headwater	WSS	0.00
Flores de Goiás	Canabrava	Quilombola	Headwater	ISS	0.00
São Miguel do Araguaia	Lageado	Settlement	Excavated shallow tube	ISS	8.80
Flores de Goiás	Canabrava	Quilombola	Headwater	ISS	0.00
Flores de Goiás	Canabrava	Quilombola	Headwater	ISS	0.00
Flores de Goiás	Canabrava	Quilombola	Headwater	ISS	0.00
Flores de Goiás	Canabrava	Quilombola	Headwater	ISS	0.00
São Miguel do Araguaia	Lageado	Settlement	Excavated shallow tube	ISS	2,90
Niquelândia	Povoado Vermelho	Quilombola	Headwater	ISS	0.00
São Miguel do Araguaia	Lageado	Settlement	Excavated shallow tube	ISS	0.40
Niquelândia	Povoado Vermelho	Quilombola	Headwater	WSS	0.00
Professor Jamil	Rochedo	Settlement	Headwater	ISS	0.00
Barro Alto	Santo Antônio da Laguna	Quilombola	Headwater	ISS	0.00
Silvânia	São Sebastião da Garganta	Settlement	Excavated shallow tube	ISS	0.00
Campos Belos	Taquarussu	Quilombola	Excavated shallow tube	ISS	0.00
Professor Jamil	Rochedo	Settlement	Excavated shallow tube	ISS	0.00
Professor Jamil	Rochedo	Settlement	Excavated shallow tube	ISS	0.00
São Miguel do Araguaia	Lageado	Settlement	Excavated shallow tube	ISS	4.10
São Miguel do Araguaia	Lageado	Settlement	Excavated shallow tube	ISS	0.10
São Miguel do Araguaia	Lageado	Settlement	Excavated shallow tube	ISS	4.90
Professor Jamil	Rochedo	Settlement	Excavated shallow tube	ISS	0.10
Professor Jamil	Rochedo	Settlement	Excavated shallow tube	ISS	0.10
Professor Jamil	Rochedo	Settlement	Excavated shallow tube	ISS	0.00
Silvânia	São Sebastião da Garganta	Settlement	Excavated shallow tube	ISS	0.00
Nova Crixás	Landi	Riparian	Excavated shallow tube	ISS	0.00

It continues...

Appendix 1 – Continuation.

Municipality	Rural Community	Community Typology	Water Supply Source	Supply System	Nitrate Concentration in Water (mg/L)
Professor Jamil	Rochedo	Settlement	Excavated shallow tube	ISS	0.10
Professor Jamil	Rochedo	Settlement	Excavated shallow tube	ISS	0.90
Nova Crixás	Landi	Riparian	Excavated shallow tube	ISS	0.00
Nova Crixás	Landi	Riparian	Excavated shallow tube	ISS	0.00
Professor Jamil	Rochedo	Settlement	Excavated shallow tube	ISS	0.20
Professor Jamil	Rochedo	Settlement	Excavated shallow tube	ISS	0.10
Água Limpa	Arraial da Ponte	Riparian	Excavated shallow tube	ISS	1.10
Silvânia	São Sebastião da Garganta	Settlement	Excavated shallow tube	ISS	1.20
Nova Crixás	Landi	Riparian	Excavated shallow tube	ISS	0.50
Nova Crixás	Landi	Riparian	Excavated shallow tube	ISS	2.70
Barro Alto	Santo Antônio da Laguna	Quilombola	Excavated shallow tube	ISS	0.60
Barro Alto	Santo Antônio da Laguna	Quilombola	Excavated shallow tube	ISS	2.50
Barro Alto	Santo Antônio da Laguna	Quilombola	Excavated shallow tube	ISS	0.40
Barro Alto	Santo Antônio da Laguna	Quilombola	Excavated shallow tube	ISS	2.40
Barro Alto	Santo Antônio da Laguna	Quilombola	Excavated shallow tube	ISS	0.40
Padre Bernardo	Sumidouro	Quilombola	Excavated shallow tube	ISS	1.60
Padre Bernardo	Sumidouro	Quilombola	Excavated shallow tube	ISS	6.60
Padre Bernardo	Sumidouro	Quilombola	Excavated shallow tube	ISS	2.20
Posse	Baco Pari	Quilombola	Deep tube well (artesian)	WSS	0.40
Nova Crixás	Landi	Riparian	Excavated shallow tube	ISS	0.00
Padre Bernardo	Sumidouro	Quilombola	Excavated shallow tube	ISS	0.00
Simolândia	Castelo Retiro Três Rios	Quilombola	Deep tube well (artesian)	WSS3	0.20
Iaciara	Extrema	Quilombola	Deep tube well (artesian)	WSS	1.30
Divinopolis de Goiás	Vazante	Quilombola	Deep tube well (artesian)	WSS2	1.80
Monte Alegre de Goiás	Pelotas	Quilombola	Deep tube well (artesian)	ISS	0.10
Flores de Goiás	Canabrava	Quilombola	Deep tube well (artesian)	WSS1	0.10
Goianésia	Itajá 2	Settlement	Deep tube well (artesian)	ISS	0.30
Professor Jamil	Rochedo	Settlement	Deep tube well (artesian)	ISS	0.80
Professor Jamil	Rochedo	Settlement	Deep tube well (artesian)	ISS	0.40
Professor Jamil	Rochedo	Settlement	Deep tube well (artesian)	ISS	0.40
Professor Jamil	Rochedo	Settlement	Deep tube well (artesian)	ISS	4.50
Professor Jamil	Rochedo	Settlement	Deep tube well (artesian)	ISS	3.90
Uruaçu	São Lourenço	Settlement	Excavated shallow tube	ISS	0.00
Silvânia	João de Deus	Settlement	Deep tube well (artesian)	ISS	0.00
Simolândia	Castelo Retiro Três Rios	Quilombola	Deep tube well (artesian)	WSS1	0.00
Professor Jamil	Rochedo	Settlement	Deep tube well (artesian)	ISS	2.20
Goiandira	Povoado Verissimo	Riparian	Deep tube well (artesian)	WSS	0.90
Barro Alto	Santo Antônio da Laguna	Quilombola	Deep tube well (artesian)	ISS	0.10
Padre Bernardo	Sumidouro	Quilombola	Deep tube well (artesian)	ISS	0.10
Mineiros	Pouso Alegre de Goiás	Settlement	Deep tube well (artesian)	WSS	0.10

It continues...

Appendix 1 – Continuation.

Municipality	Rural Community	Community Typology	Water Supply Source	Supply System	Nitrate Concentration in Water (mg/L)
Simolândia	Castelo Retiro Três Rios	Quilombola	Deep tube well (artesian)	WSS4	0.00
Gameleira	Olhos d'Água	Riparian	Shallow tube well (mini-well)	WSS	0.80
Simolândia	Castelo Retiro Três Rios	Quilombola	Deep tube well (artesian)	WSS2	0.00
Divinopolis de Goiás	Vazante	Quilombola	Deep tube well (artesian)	WSS1	0.00
Cavalcante	São Domingos	Quilombola	Deep tube well (artesian)	WSS	0.00
Flores de Goiás	Canabrava	Quilombola	Deep tube well (artesian)	ISS	0.00
Gameleira	Olhos d'Água	Riparian	Shallow tube well (mini-well)	ISS	6.60
Gameleira	Olhos d'Água	Riparian	Shallow tube well (mini-well)	ISS	0.10
Flores de Goiás	Canabrava	Quilombola	Deep tube well (artesian)	ISS	0.00
Silvânia	João de Deus	Settlement	Shallow tube well (mini-well)	ISS	0.10
Goianésia	Itajá 2	Settlement	Deep tube well (artesian)	ISS	0.00
Barro Alto	Santo Antônio da Laguna	Quilombola	Deep tube well (artesian)	ISS	0.00
Silvânia	João de Deus	Settlement	Shallow tube well (mini-well)	ISS	0.50
Silvânia	São Sebastião da Garganta	Settlement	Shallow tube well (mini-well)	ISS	2.20
Silvânia	São Sebastião da Garganta	Settlement	Shallow tube well (mini-well)	ISS	0.20
Silvânia	São Sebastião da Garganta	Settlement	Shallow tube well (mini-well)	ISS	0.10
Silvânia	São Sebastião da Garganta	Settlement	Shallow tube well (mini-well)	ISS	0.20
Silvânia	São Sebastião da Garganta	Settlement	Shallow tube well (mini-well)	ISS	0.30
Padre Bernardo	Sumidouro	Quilombola	Deep tube well (artesian)	ISS	0.00
Gameleira	Olhos d'Água	Riparian	Shallow tube well (mini-well)	ISS	0.00
Silvânia	João de Deus	Settlement	Shallow tube well (mini-well)	ISS	0.00
São Miguel do Araguaia	Lageado	Settlement	Shallow tube well (mini-well)	ISS	11.6
Silvânia	João de Deus	Settlement	Shallow tube well (mini-well)	ISS	0.00
São Miguel do Araguaia	Lageado	Settlement	Shallow tube well (mini-well)	ISS	8.00
Professor Jamil	Rochedo	Settlement	Shallow tube well (mini-well)	ISS	0.20
Professor Jamil	Rochedo	Settlement	Shallow tube well (mini-well)	ISS	1.30
Monte Alegre de Goiás	Pelotas	Quilombola	Shallow tube well (mini-well)	ISS	0.00
Nova Crixás	Landi	Riparian	Shallow tube well (mini-well)	ISS	6.50
Nova Crixás	Landi	Riparian	Shallow tube well (mini-well)	ISS	0.00
Uruaçu	São Lourenço	Settlement	Shallow tube well (mini-well)	ISS	0.00
Uruaçu	São Lourenço	Settlement	Shallow tube well (mini-well)	ISS	0.00
Uruaçu	São Lourenço	Settlement	Shallow tube well (mini-well)	ISS	0.00
Uruaçu	São Lourenço	Settlement	Shallow tube well (mini-well)	ISS	0.00
Barro Alto	Santo Antônio da Laguna	Quilombola	Shallow tube well (mini-well)	ISS	0.10
Uruaçu	São Lourenço	Settlement	Shallow tube well (mini-well)	ISS	0.00
Uruaçu	São Lourenço	Settlement	Shallow tube well (mini-well)	ISS	0.00
Uruaçu	São Lourenço	Settlement	Shallow tube well (mini-well)	ISS	0.70
Uruaçu	São Lourenço	Settlement	Shallow tube well (mini-well)	ISS	0.00
Uruaçu	São Lourenço	Settlement	Shallow tube well (mini-well)	ISS	0.00
Uruaçu	São Lourenço	Settlement	Shallow tube well (mini-well)	ISS	0.40

WSS: water supply system; ISS: individual alternative solution.