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ACUTE DIARRHEAL DISEASES AND THEIR RELATIONSHIP WITH WATER QUALITY IN ARAGUATINS, TOCANTINS, BRAZIL: A CROSS-SECTIONAL STUDY

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Abstract
Diarrhea remains a significant cause of death worldwide among children under five years old. In Brazil, the highest incidence of the disease occurs in the north region, and the epidemiological characteristics of diarrhea in Araguatins, TO, northern Brazil, have not been reported. The present study aimed to analyze the occurrence of acute diarrheal diseases (ADD) in Araguatins between 2014 and 2019 and its relationship with the quality of the public water supply. The study also analyzed the correlation between ADD frequency and rotavirus vaccination coverage of children. The data were obtained from the Brazilian Ministry of Health (SIVEP-DDA database) and the Health Surveillance Agency of Araguatins. The reported cases of acute diarrheal diseases significantly increased in 2018 and 2019 compared to the other years, and the occurrence of greater severity in the age group of ≥10 years increased in the same period. The highest incidence of diarrhea occurred in 2018 when the application of rotavirus vaccines to children was the lowest. In most years investigated, the cases of acute diarrheal diseases occurred in both rainy and dry periods. However, in 2016, diarrhea cases were concentrated in the dry period, and *Escherichia coli* and total coliforms were found more frequently in the public water supply. The highest frequency of contamination with *E. coli* and total coliforms occurred in the Downtown area. The conclusion was that diarrheal disease may be caused, at least partially, by water-conveying agents in the treated public water supply of the Araguatins.

Keywords: Rainfall. Water pollution. Waterborne diseases.

1. Introduction

Acute diarrheal diseases (ADD) are characterized by at least three episodes of acute diarrhea in 24 hours with nausea, vomiting, abdominal pain, fever, and loss of water and electrolytes such as sodium, potassium, chloride, and bicarbonate (SBP 2017). The consequences associated with these losses are dehydration, hypovolemic shock, and hypopotassemia. Diarrhea may be caused by bacteria, viruses, and other parasites such as protozoa that generate gastroenteritis (Ilancheran 2020).

The Global Burden of Diseases Study analyzed 195 countries regarding morbidity, mortality, and the etiology of diarrhea and indicated that, in 2016, diarrhea was the fifth and eighth leading cause of death among children under five years old and individuals of all ages, respectively. The cause of death among children under five years old was attributed mainly to rotavirus and for those over five years old to *Shigella sp* (Troeger et al. 2018).

Isolated cases that do not characterize an outbreak do not require notification but ADD outbreaks must be reported when treated in local basic health units. These health units inform the Municipal Health Department, which must notify the Epidemiological Surveillance Service where the data is entered into the ADD Computerized System of Epidemiological Surveillance, known by the SIVEP-DDA acronym (Brasil 2019). In the state of Tocantins, the basic health units must make the notifications by filling out forms and insertions in the SIVEP-DDA database (Tocantins 2015). The occurrence of outbreaks or at least two cases with the same clinical condition of diarrhea after ingesting food or water from the same origin characterizes water- or foodborne disease outbreak. In this case, reporting is compulsory and immediate (up to 24 hours) to the Notifiable Diseases Information System (SINAN) within seven days (Brasil 2019).

Diarrhea and infectious gastroenteritis were the second leading cause of death from infectious and parasitic diseases among men and the third among women between 2010 and 2012 in the state of Tocantins (Paixão et al. 2017). Diarrhea could be related to the quality of the water consumed (Forgiarini et al. 2018), basic sanitation, and the access and quality of health services (de Oliveira and de Latorre 2010).

In Tocantins, diarrhea caused an average of 502 hospitalizations per year of children between zero and four years old, with an annual rate of 4.1 cases per 1,000 inhabitants from 2008 to 2013, and the highest prevalence of cases occurred in Araguaína (Fontoura et al. 2018).

Araguatins is in the microregion called "Bico do Papagaio" in Tocantins, northern Brazil, whose estimated population in 2020 was 36,170 inhabitants. The municipality had 1.8% of residences connected to the sanitary sewage system (data from 2010) and 2.4 hospitalizations for diarrhea per 1,000 inhabitants (data from 2016) (IBGE 2021). In 2016, there were seven basic health units, one general hospital, one health center, four support units for diagnosis and therapy, 25 hospitalization beds within the public health network, and two Health Surveillance units, and the leading cause of death among residents was cardiovascular disease (Tocantins 2017). The public water supply source is the Taquari River (ANA 2010), along which there are pasture areas (de Paula Carvalho et al. 2007; Tocantins 2017) with a risk of water contamination by zoonosis. Other environmental problems have been reported, such as using river water to dilute sewage from commercial and industrial activities, waste disposal, and removal of riparian forests for agriculture (de Paula Carvalho et al. 2007).

Considering the literature has not reported the causes of diarrhea and its associated factors in Araguatins, this study aimed to analyze the occurrence of ADD in different age groups of the population in the municipality from 2014 to 2019 and correlate these data to the quality of water supply and the rotavirus vaccination coverage.

2. Material and Methods

Study design and data collection

For this cross-sectional and observational study, ADD reports in Araguatins from 2014 to 2019 were searched in the SIVEP-DDA database, and access was requested from the Municipal Health Department. The retrieved data contained the number of cases in each age group (<1, 1 to 4, 5 to 9, and ≥10 years old) and in different epidemiological weeks. Moreover, the number of individuals treated for diarrhea who received treatment plans A, B, or C, as described by the World Health Organization (WHO), were also retrieved. Plan A is for patients with diarrhea but not dehydrated, who can be treated at home with an oral rehydration solution. If the patient has diarrhea and dehydration, Plan B is indicated, which comprises oral rehydration therapy at a health care facility. Plan C is used for severe dehydration, in which rehydration is done parenterally (Brasil 2019; SBP 2017). This study was approved by the Human Research Ethics Committee of the University of Taubaté (CAEE 29529520.3.0000.5501).

The data on water quality analyses were obtained from the Sanitary Surveillance Agency of Araguatins. Water turbidity values were expressed as uT (turbidity), a unit used in the Brazilian standards of water quality for human consumption (Brasil 2017; Brasil 2021), equivalent to Nephelometric Turbidity Units (NTU). The data on the presence or absence of total coliforms and *E. coli* and sample collection sites were also supplied.

The Brazilian Institute of Meteorology (INMET) databases (https://bdmep.inmet.gov.br) provided the rainfall data.

The incidence of ADD was calculated as the average number of cases in each epidemiological week per 1,000 inhabitants. Epidemiological weeks were defined according to the epidemiological calendar available on the Brazilian Ministry of Health website (http://portalsinan.saude.gov.br/calendario-epidemiologico-2019/43-institucional).

The total number of inhabitants of Araguatins each year was obtained from the population estimate of the Federal Court of Auditors available on the DATA-SUS website (http://tabnet.datasus.gov.br/cgi/deftohtm.exe?ibge/cnv/poptto.def).

The DATA-SUS database (http://tabnet.datasus.gov.br/cgi/dhdat.exe?bd_pni/cpnibr.def) provided data on the human rotavirus vaccine coverage in Araguatins from 2014 to 2019.

Statistical analyses

Statistical analyses were performed with the Statistical Package for Social Science (SPSS), version 26.0 for Windows (IBM, Chicago, USA). Non-parametric tests were used when the data presented a non-normal distribution after the Kolmogorov-Smirnov test.

The frequencies were analyzed with the Chi-square test associated with the post-hoc test with Bonferroni correction (MacDonald and Gardner 2000).

The ADD incidence and water turbidity data were analyzed with the Kruskal-Wallis test, followed by the Nemenyi test for multiple comparisons. The Mann-Whitney test was applied to compare turbidity values in the presence of total coliforms or *E. coli.* All statistical analyses were set at a 5% significance level (α).

3. Results

Water is one of the main contamination routes of etiological agents of ADD. The presence of total coliforms and *E. coli* indicates poor water quality, and this study detected them in all investigated years. Total coliforms were in 3.0, 4.6, 23.2, 13.7, 9.2, and 4.0% of the sampling in 2014, 2015, 2016, 2017, 2018, and 2019, respectively. *Escherichia coli* was in 0.7, 12.8, 3.2, 2.6, and 0.8% in 2014, 2016, 2017, 2018, and 2019, respectively. *E. coli* was not detected in 2015 samplings. Therefore, the presence of both total coliforms and E. coli was highest in 2016 compared to the other years. The mean occurrences of total coliforms and *E. coli* were 9.6 and 3.4% in a year, respectively. Therefore, total coliforms were detected more often than *E. coli*.

The water potability standard requires the absence of total coliforms in 100 mL of water in 95% of the samples examined in a month if the distribution network supplies more than 20,000 inhabitants (Brasil 2017; Brasil 2021). In 2016, 2017, and 2018, total coliforms were in more than 5% of monthly samplings, higher than the permitted rate. This situation was observed in all samplings in 2016, six of nine samplings in 2017 (in epidemiological weeks three, seven, 12, 16, 29, and 47), and seven of 11 samplings in 2018 (Figure 1). There were no detections from October to December 2016; in May, June, and December 2017; and in June 2018. Total coliforms were not detected in some samplings in the dry season in 2017 (in epidemiological weeks 34, 38, and 42) and appeared in the rainy season (Figure 1). However, the numbers of ADD cases were similar in both seasons. These results indicate that ADD cases occur even if water quality is acceptable. A similar phenomenon occurred in 2018, when the microbiological quality of water was good in the rainy season (between epidemiological weeks eight and 13) but the number of ADD cases was high. The presence of *E. coli* was high in 2016, and it was absent only in the samplings of epidemiological weeks three, seven, and 15 (Figure 1). *E coli* was also present in several epidemiological weeks in 2017 and 2018, usually when total coliforms also appeared.

The water analysis also indicated that, in 2016, turbidity was low compared to the other years and significantly lower than in 2014 and 2018 (Figure 2A). No turbidity data were obtained in 2019. Water turbidity was analyzed in all samples containing total coliforms or *E. coli* between 2014 and 2018 (Figure 2B). Turbidity was lower in waters with microorganisms and not the opposite, as expected.

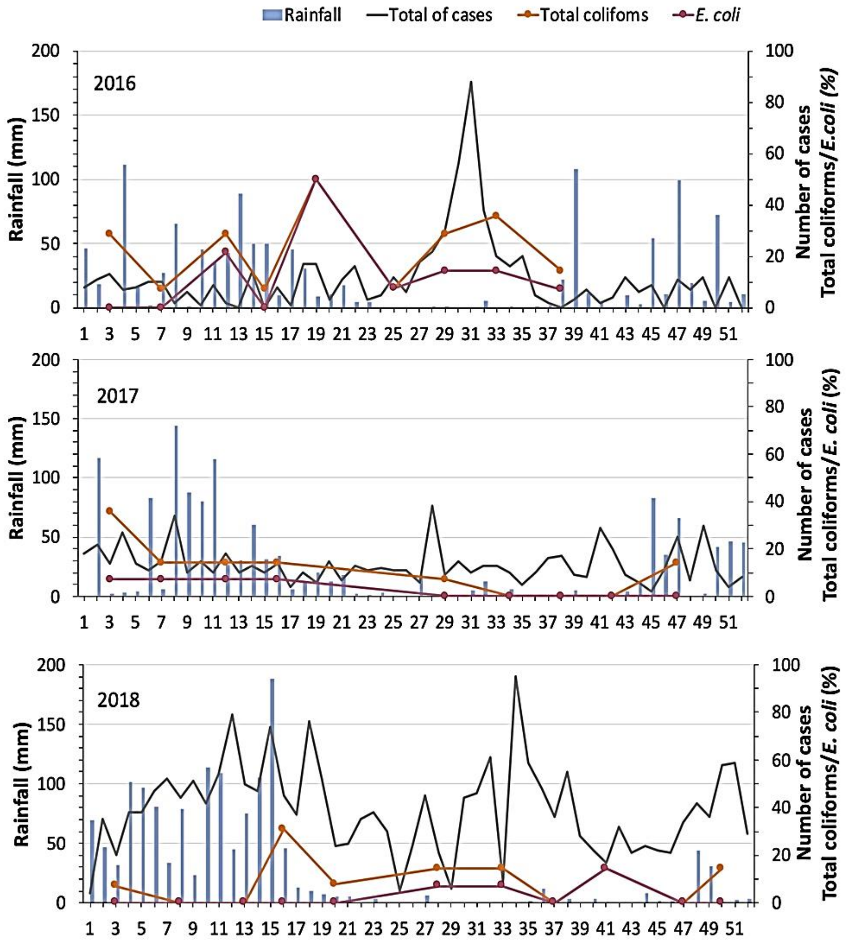

Figure 1. Frequency (%) of total coliforms and *E. coli* detected in the sampling performed throughout the epidemiological weeks; rainfall level and number of ADD cases in 2016, 2017 and 2018 in Araguatins. Total ADD cases corresponds to the sum of the cases occurred across all age ranges.

Figure 3 shows the locations of Araguatins where total coliforms or *E. coli* were detected from 2014 to 2019. The site most frequently contaminated with total coliforms or *E. coli* was the Downtown area (Centro), and the less contaminated was Araguaia Avenue (Av Araguaia).

The number of ADD cases was distributed throughout the year in all age groups except for 2016 (Figure 4). In that year, there was a peak between epidemiological weeks 30 and 31 (July 24, 2016 and August 06, 2016) in all age groups. This period coincided with the dry season in Araguatins. Also, during the peak of 2016, ADD occurrence was higher in the age group of one to four years. Since 2018, the cases prevailed in the age group of 10 years or older. In 2019, they also peaked among children under one year old in week 31, in low rainfall.

From 2014 to 2017, about 30% of ADD cases occurred in children aged one to four years, but in 2018 and 2019, about 50% affected ≥10-year-olds. In 2014, 2015, and 2017, the cases among children under one year old were higher than statistically expected. The same phenomenon occurred in 2016 and 2017 in children aged five to nine years.

Plan A was the most common treatment, meaning that most cases were not severe and without dehydration (Figure 5A). However, in 2016, 2018, and 2019, the cases worsened, showing a significant increase in plan B, recommended for dehydration. The frequency of severe cases requiring plan C was low or non-existent in most years investigated. Only in 2016, there was a higher occurrence, with 4.3% of patients undergoing plan C. In the same year, plan B was most performed in the peak of cases (week 31) and plan C in the weeks before or after this peak (Figure 5B). In 2018, plan B was used from week 23 onwards. In 2019, plan B was used throughout the year, and plan C was used in week 31 when cases peaked among children under one year old (Figures 4 and 5). However, the SIVEP/DDA data do not allow assessing what age group received each treatment, and it is impossible to affirm that children under one year old showed higher severity at that time. It is worth noting that, in 2018, ADD cases with dehydration, which require plan B, mainly occurred in the dry period, as in 2016 (Figures 4 and 5). In 2019, despite the more uniform distribution of cases requiring plan B, the use of this plan tended to increase in the dry season, between epidemiological weeks 31 and 40.

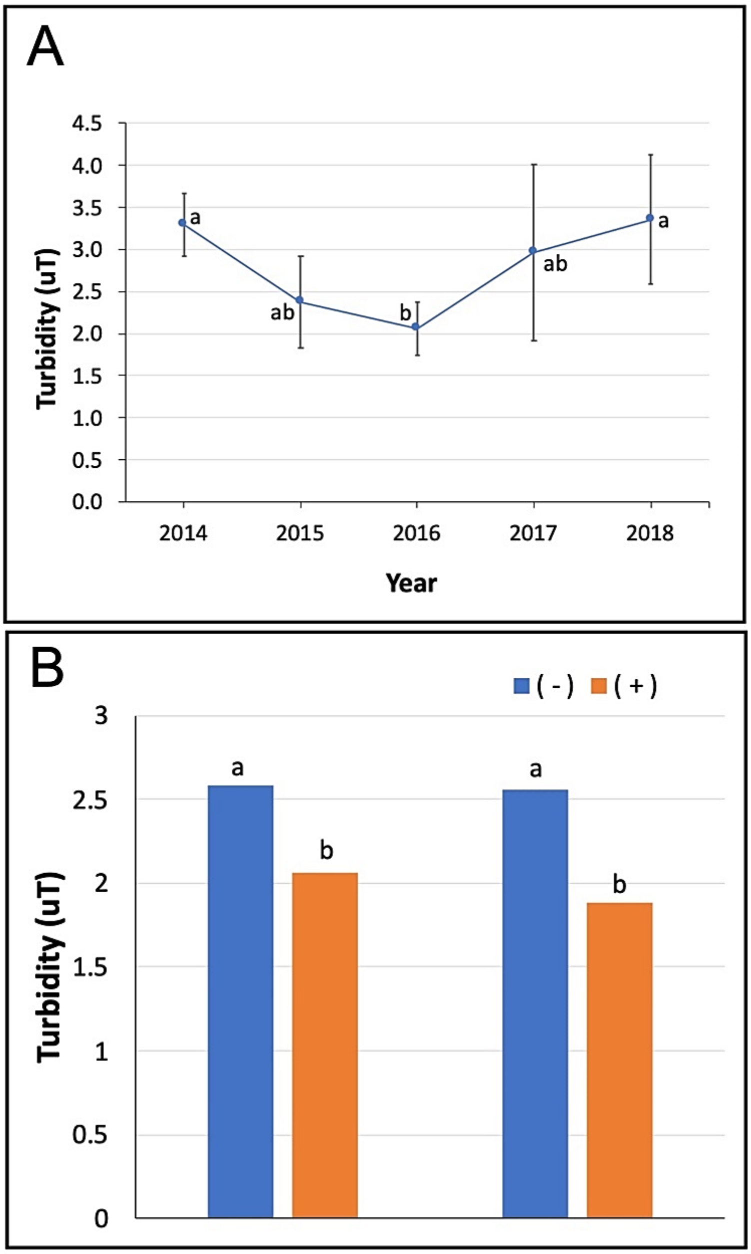

Figure 2. A – Turbidity of the water samples in the period from 2014 to 2018. The bars represent a confidence interval (95%). Different letters indicate a significant difference among years (Kruskal-Wallis test followed by Nemenyi test, $p < 0.05$). B – Turbidity of the water samples with (+) or without (-) total coliforms or *E. coli* in the same period. Different letters indicate a significant difference (Mann-Whitney test) in turbidity between samples with or without total coliforms ($p < 0.001$) or *E. coli* ($p < 0.01$). uT = unit of turbidity.

The average incidence of ADD showed an increasing trend since 2016. In 2017, it increased approximately twice compared to 2015, although there were no statistical differences from 2014 to 2017 (Figure 6). ADD incidence increased almost three times between 2017 and 2018, and in 2018, it statistically differed from the other years. In 2019, there was a drop compared to 2018, but the incidence was still significantly higher compared to 2014 - 2017. In 2018, vaccination coverage was the lowest (67.72%) and coincided with the year of the highest ADD occurrence in Araguatins. In 2018, most cases occurred among individuals over 10 years old (50.4%), followed by the age group of one to four years (28.5%). In 2019, HRV vaccination coverage increased relative to 2018, and the patterns among groups were repeated (Figure 6).

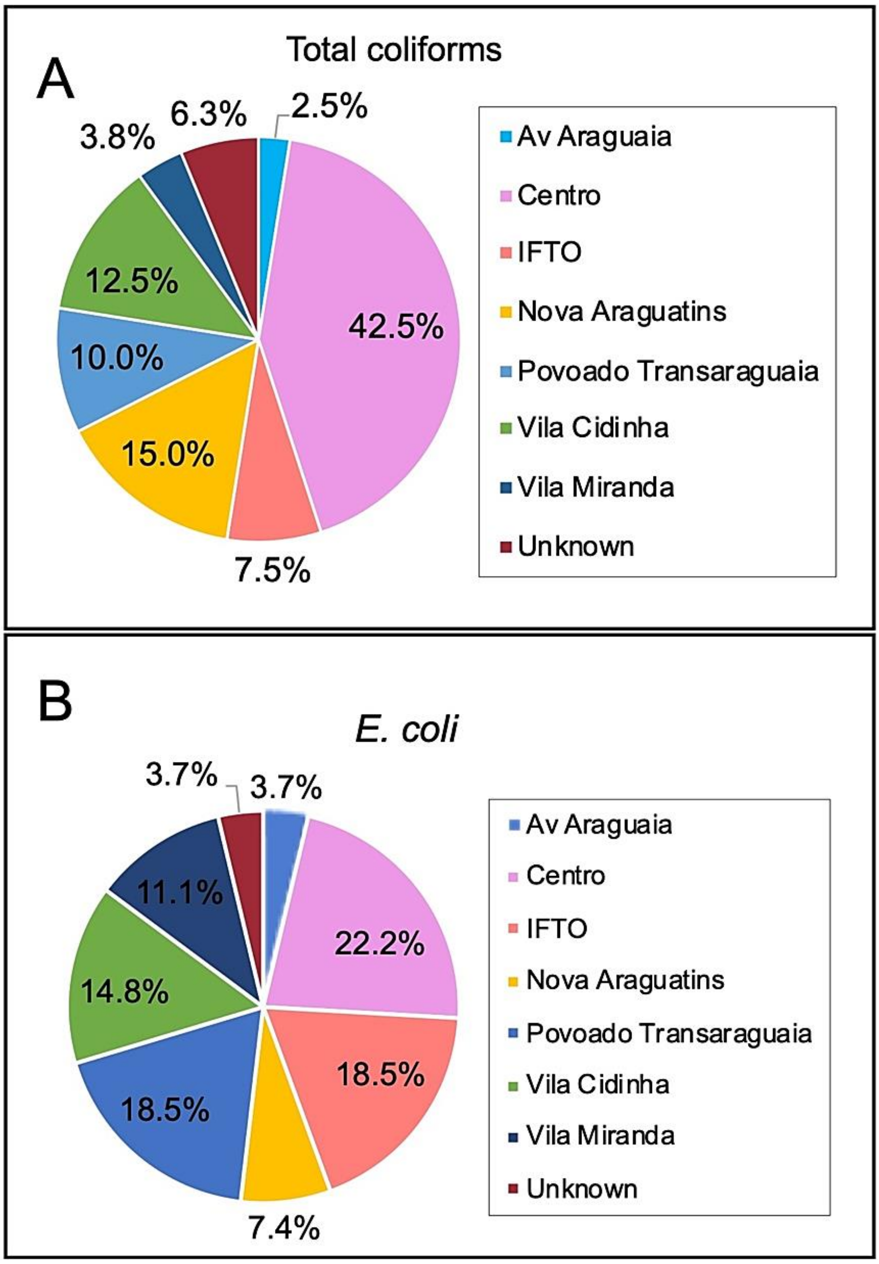

Figure 3. Relative frequency (%) of the sites presenting contamination between 2014 and 2019 in the municipality of Araguatins. A – Contamination by total coliforms. B – Contamination by *E. coli*. Unknown refers to an unidentified sector in the municipality due to incomplete registration of addresses during sampling. IFTO = Federal Institute of Tocantins.

4. Discussion

Acute diarrheal disease (ADD) may be seasonal due to several climatic, social, nutritional, economic, and cultural factors, such as unhealthy hygiene conditions, direct contact with infected people, early weaning, the lack of basic sanitation, regional festivals, and rainfall (de Queiroz et al. 2009).

In Brazil, seasonal mortality patterns for children under five years old have changed over the years (Baker and Alonso 2018). In the 1980s, mortality peaked from December to April (summer and early autumn). Between 2000 and 2005 (pre-vaccine period for rotavirus), it peaked from June to October (winter and early autumn). Between 2007 and 2014 (ongoing rotavirus vaccination), high mortality rates returned in the summer and early autumn. In north and northeast regions of Brazil, in equatorial states, the peaks of deaths were distributed throughout the year, with higher risks in the autumn.

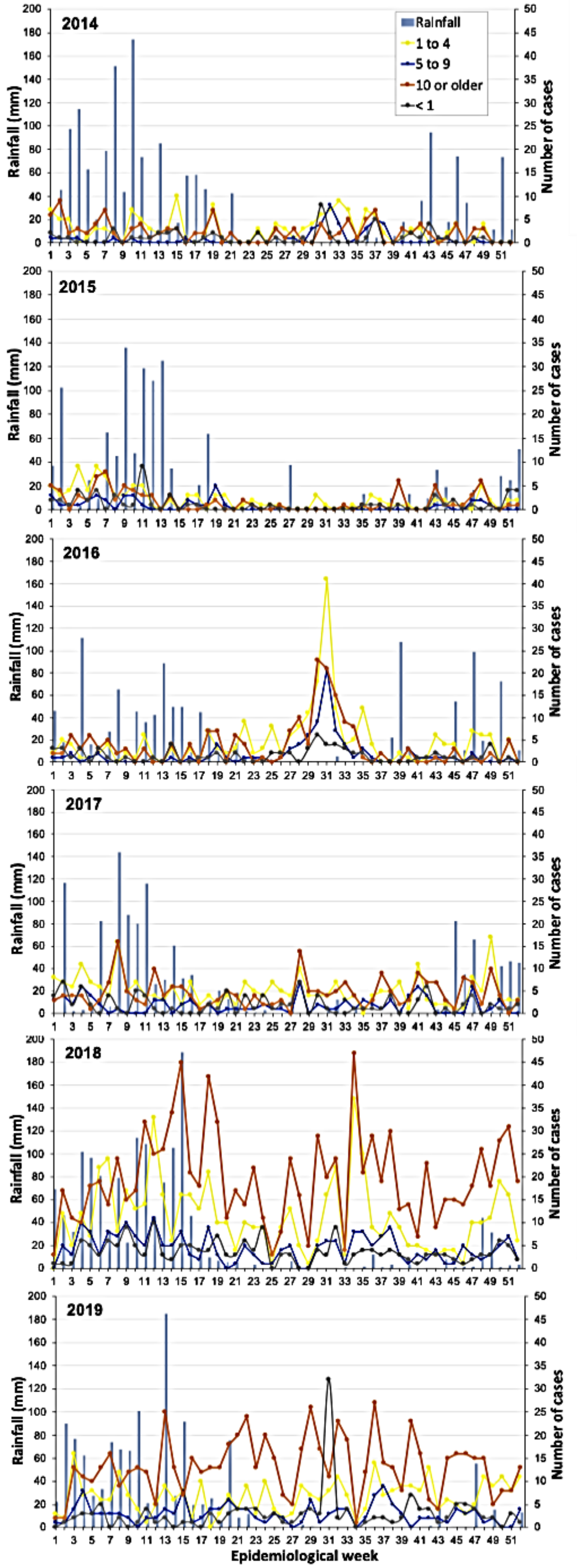

Figure 4. Rainfall and number of ADD cases in different years according to age group, in the different epidemiological weeks.

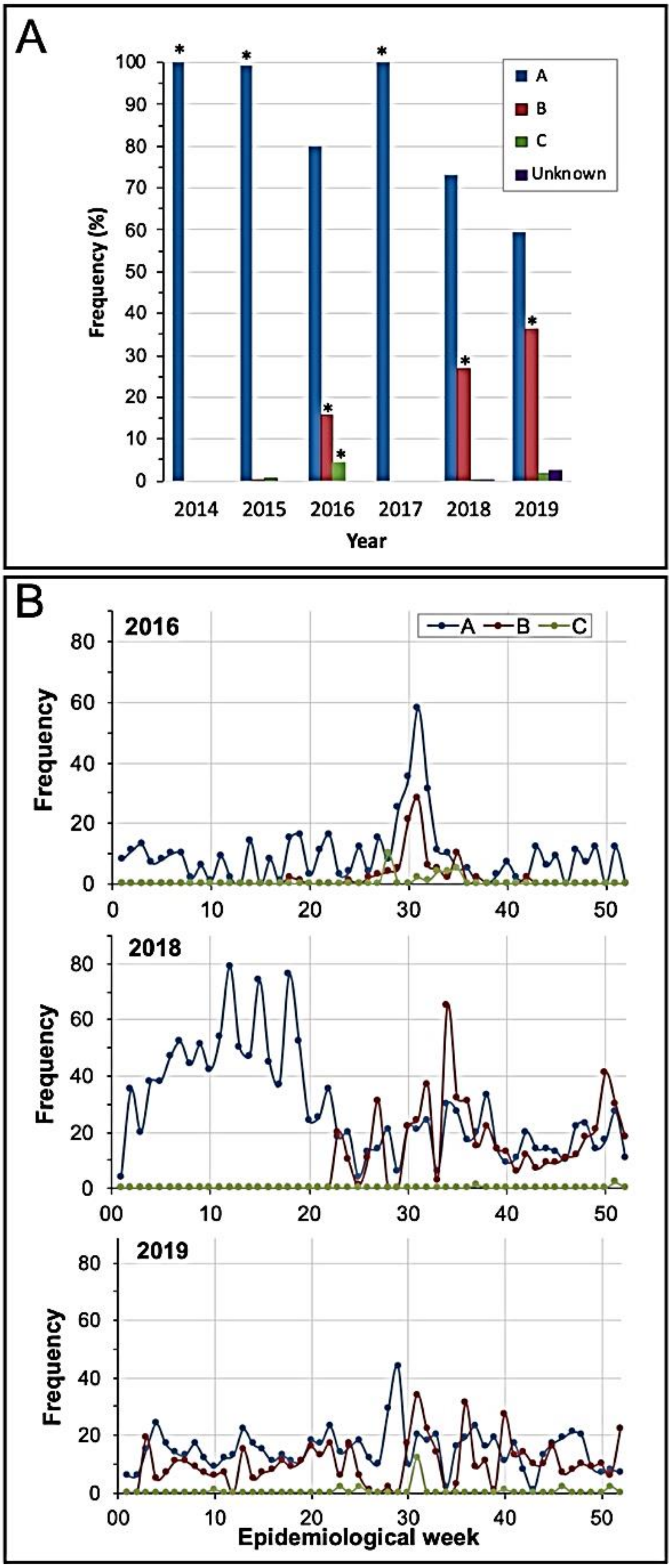

Figure 5. A – Frequency of treatments (plans A, B and C) in Araguatins from 2014 to 2019. The asterisks indicate significant variation (Chi-square, $p<0.001$). B – Frequency of the treatments throughout epidemiological weeks, in the years 2016, 2018 and 2019.

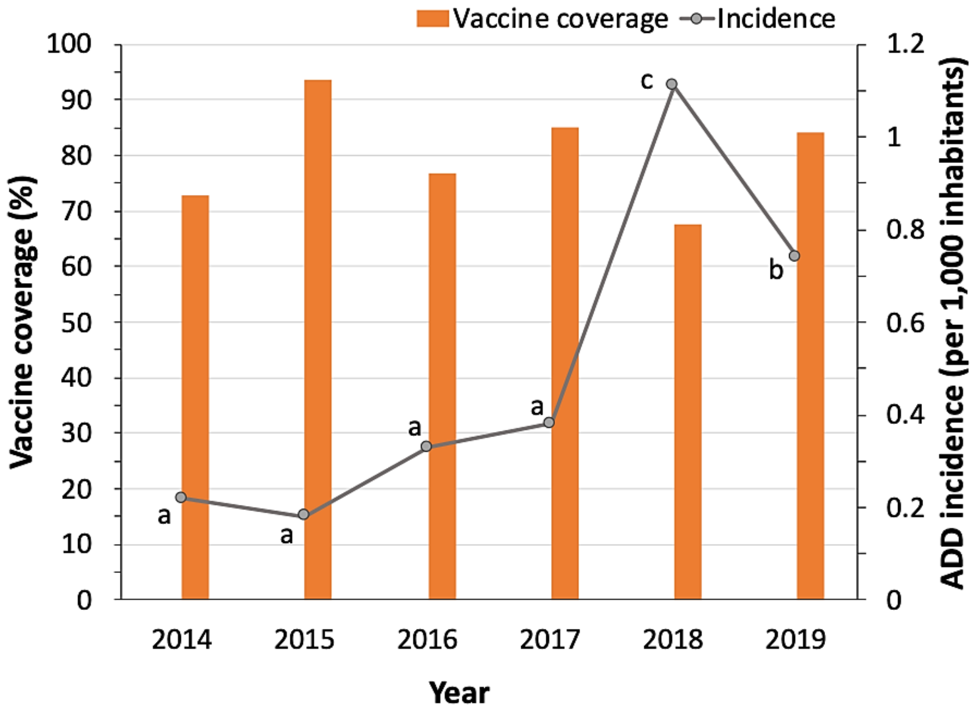

Figure 6. Average incidence of ADD and coverage of human rotavirus vaccine in Araguantins in the period 2014 to 2019. Different letters indicate a significant difference among years (Kruskal-Wallis test followed by Nemenyi test, $p<0.001$).

The rotavirus incidence in tropical regions may occur throughout the year because climatic conditions in the tropics are relatively constant compared to temperate areas (Levy et al. 2009). In Araguatins, ADD occurrences are usually distributed throughout the year. The exception was 2016 when cases were concentrated in epidemiological weeks 30 and 31. The dry season in Araguatins occurs during these weeks when the mean relative air humidity and temperature are around 43% and 27.8ºC, respectively. These meteorological data are from July 24 and 25, 2016, because it was the only information available within these epidemiological weeks, according to INMET. The survival rate and lifetime of the rotavirus are higher with relative humidity (RH) of 50 ± 5% compared with higher (80% RH) or lower (25% RH) values in the air at 20ºC. The same pattern occurred at lower temperatures (6ºC) (Sattar et al. 1984; Ijaz et al. 1985). ADD cases probably peaked in 2016 because environmental conditions favored rotavirus survival. However, the literature has no data analyzing rotavirus survival in the relative humidity and temperature range of Araguatins.

In 2016, microbiological contamination was higher than the other years, but it occurred throughout the year. Then, the peak ADD between epidemiological weeks 30 and 31 had no obvious correlation to water contamination. In 2019, there was an increase in ADD cases in children under one year old in epidemiological week 31. This increase coincided with a period of low rainfall and relative humidity. Levy et al. (2009) highlight that, in tropical countries, rotavirus infections may occur in mild temperatures and dry seasons.

The human rotavirus (HRV) vaccine is indicated for children from six weeks old (WHO 2013). The vaccine aims to prevent severe cases and reduce hospitalizations and deaths. The recommended HRV vaccination coverage is at least 90% (Salvador et al. 2011), but this rate was reached only in 2015 and was lower in the other years in Araguatins. Rotavirus can be transmitted by fecal-oral contact, respiratory spread, and contaminated water and food (Brasil 2019).

According to Luchs et al. (2014), rotavirus is found most often in fecal samples of children, but also of adults with ADD. Studies conducted in the USA indicated that vaccinating children with HRV decreases the prevalence of rotavirus in adults, suggesting indirect protection of adults. However, the same authors state that this has not been observed in Brazil, and adults may be the carriers of rotaviruses that contaminate children. In Araguatins, ADD incidence in the overall population increases as vaccine coverage decreases; therefore, vaccinating children might protect populations of other age groups.

The presence of total coliforms in water is used to evaluate the quality of water treatment. Total coliforms are gram-negative bacilli in the microbiota of the human gastrointestinal tract and some animals. However, the presence of total coliforms does not necessarily mean fecal contamination, as this group includes several bacteria found in soil and water. Coliform bacteria may not be pathogenic but can indicate the presence of pathogenic microbes and the potential efficacy of water treatment services (Nabeela et al. 2014).

The microbiological quality of the water supplied to the municipality did not comply with the established legislation, particularly in 2016, 2017, and 2018. This result suggests that other microorganisms that were not analyzed, including the rotavirus, could also be in the water.

Although the microbiological quality of water improved in 2019, ADD cases were still high compared to the other years, except for 2018. A new technique of virus inactivation analysis with cell culture integrated with RT-qPCR has reevaluated rotavirus resistance to chlorine disinfection. This technique revealed that rotaviruses may be more resistant to chlorine than initially thought, and the risk of their presence in the environment may be underestimated (Li et al. 2011).

The presence of *E. coli* in the water of Araguatins is also a relevant indication of the cause of ADD. The Brazilian Ministry of Health (Brasil 2017; Brasil 2021) establishes that water for human consumption should not contain *E. coli* in a 100-mL sample. Enteropathogenic *E. coli* (EPEC) is a diarrheagenic category of *E. coli* and one of the leading causes of diarrhea in children and adults. EPEC is present in several populations and has been adapting to the environment so that two sub-categories can be currently distinguished within this group: EPEC-t and EPEC-a. EPEC-t was associated only with childhood diarrhea and predominantly replaced with EPEC-a, which has caused recent outbreaks in humans at different locations (Souza et al. 2016).

Water turbidity is also a determinant of water quality, and the acceptable level is below 5.0 NTU or 5.0 uT. However, due to the risks associated with *Cryptosporidium* spp., the enforced rules determine lower levels, at a maximum of 0.5 uT in at least 95% of monthly samples of filtered water produced by conventional or direct filtration, or 0.3 uT in the case of a concentration higher than 1.0 Oocystis L^{-1} of *Cryptosporidium* spp. in the source water (Brasil 2021). The turbidity of the public water supply of Araguatins was lower than 5.0 uT but higher than 2.0 uT. Therefore, it was acceptable considering the organoleptic standard for drinking water, but it may be insufficient to prevent contamination by *Cryptosporidium* spp. Several factors can affect turbidity, such as detachment of encrustations in water mains and smaller pipes, the lack of chlorine that increases turbidity, and an increased concentration of organic matter. Turbidity indicates filtration efficiency in water treatment (Brasil 2006).

Considering that water turbidity was lower in 2016, the filtration in water treatment might have been better that year. However, total coliforms and *E. coli* contaminations were also higher in the same year. Therefore, the disinfection stage might have been less efficient in water treatment stations, or there was contamination in the pipes. Moreover, turbidity was lower in waters with microorganisms and not the opposite, corroborating the hypothesis of low efficiency of the disinfection stage and/or pipe contamination with microorganisms, potentially representing risks to public health.

However, water alone cannot be the only factor causing ADD because the contamination and illness of a population can have many origins. Thus, the process should be analyzed holistically, ranging from housing conditions, daily habits, the concentration and type of pathogens ingested, the lack of basic sanitation, and the susceptibility and overall health status of those involved. Therefore, other aspects should be investigated to discriminate better the causes of ADD in Araguatins.

Only 1.8% of the population of Araguatins had a connection to a sewage network or septic tank in 2010, but this index was 67.6 % in Palmas, the capital of Tocantins (IBGE 2022). Therefore, poor basic sanitation could also contribute to ADD incidence in Araguatins.

Although the access and quality of public health care are deficient in Brazil, almost 90% of basic health units have Community Health Agents, and more than 70% have teams working five or more days a week in two shifts or more, providing nursing appointments and simple procedures such as the application of bandages for wound treatment (Facchini et al. 2018). There were no reports on the quality of care at the basic health units in Araguatins, but patients of the Municipal Hospital of Araguatins have given good reviews regarding the cleaning aspect (Ayres et al. 2015). Most ADD cases in the municipality were considered mild because the first treatment plan (Plan A) prevailed. In 2018 and 2019, the cases worsened, and plan B was used more frequently. These data suggest that people seek health care in the early stages of the pathology because treatment plan A indicates these patients do not show signs of dehydration.

Therefore, ADD cases in Araguatins probably occur due to poor basic sanitation and water quality rather than the quality of health care.

There was no specific plan to prevent ADD in Araguatins, except for the distribution of bleach for water disinfection. However, it is uncertain whether the low-income population used bleach for this purpose, considering it may also work for bleaching white clothes.

The present study supports the need for more investments in basic sanitation and improving water quality by the water supply company and municipal managers.

5. Conclusions

There is an apparent correlation between the increase in ADD cases and a reduction in HRV vaccine coverage in Araguatins. Also, microorganisms in the public water supply in the municipality were above the permitted rate, suggesting that ADD cases may have been caused, at least partially, by water-conveying agents, particularly in 2016, 2017, and 2018. Therefore, the rotavirus, *Cryptosporidium*, and/or another chlorine-resistant pathogen might have been transmitted through the water. Higher attention must be paid to the water distribution in the Downtown area, a populous region that showed frequent microbiological contamination, thus representing a risk for many people. Additionally, the Taquari River - the water source - must be protected and monitored to minimize water contamination, mainly from potentially pathogenic microorganisms.

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