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## Application of statistical control on water quality in cisterns in the semiarid Pernambucano

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### ABSTRACT

In the Brazilian semiarid region, it is necessary to use alternatives to better use water since evapotranspiration rates exceed rainfall rates, which may favor salt accumulation in cistern systems. This study aimed to investigate the water quality of cisterns from communities in the semiarid region of Pernambuco state. Thus, cistern water's physicochemical and microbiological characteristics were monitored: color, turbidity, total dissolved solids (T.D.S.), salinity through electrical conductivity (EC), pH, and total and fecal coliforms. For monitoring, statistical quality control techniques, control charts, and process capacity indices were employed. Results were found with high values for microbiological, total, and fecal coliforms in most samples. Control charts showed no abnormality in the process. The probable reason for the contamination of cistern water is the lack of cleaning of the gutters that are part of the stored water catchment system. In the northeastern semiarid population, people are looking for ways to use natural resources to ensure survival, and water quality is seen as a guarantee for the quality of life.

**Keywords:** Cistern, backwoods, physicochemical, characteristics of water, salinity.

### Introduction

The definition of aridity is based on the methodology developed by Thornthwaite (1941) with subsequent adjustment by Penman (1953) to characterize bioclimatic zones (Greve, Roderick & Seneviratne, 2017). Semiarid zones are those where the ratio between rainfall (P) and evapotranspiration (ETP) is between 0.20 and 0.50 (Moiwo & Tao, 2015). Precipitation averages in the semiarid range from 300 to 800 mm year<sup>-1</sup> and

potential evapotranspiration averages range from 1500 to 2000 mm year<sup>-1</sup>, with the region's hydrological balance distributed as follows: (a) 70% of precipitation is evaporated; (b) 20% evapotranspired, mainly by the Caatinga vegetation; (c) 10% runoff (Coelho et al., 2017).

The Brazilian semiarid is one of the wettest on the planet, with an annual average of 700 mm year<sup>-1</sup>, while in most arid zones in other countries, the annual average is 80 to 250 mm year<sup>-1</sup> (Santos

& Farias, 2017). The predominant biome in the Brazilian semiarid region is Caatinga, the only and exclusively Brazilian region. National territory and occupying the states of Bahia, Ceará, Piauí, Pernambuco, Rio Grande do Norte, Paraíba, Sergipe, Alagoas, Maranhão, besides the state of Minas Gerais that is outside the northeast region (Beuchle et al., 2015). Seasonal and periodic droughts establish intermittent river regimes and leave the vegetation without leaves (Melo et al., 2019).

However, vegetation cover is often removed, and agriculture without erosion control is implemented, promoting runoff in the rainy season, transporting sediment, and adsorbed nutrients that contribute to siltation and eutrophication of downstream rivers and dams (Silva et al., 2015). However, dry season water scarcity associated with evapotranspiration's natural process leads to low dilution capacity, which may result in extreme deterioration of water quality and elimination of natural biological communities (Piscoya et al., 2018).

Regarding the main problems related to water quality in the Brazilian semiarid, the following stand out: a) salinization of water bodies, with a particular incidence in some reservoirs; b) high levels of turbidity and siltation in important basins; c) the increasing process of pollution of water resources, caused mainly by domestic, industrial sewage, slaughterhouses, garbage, chemical and pesticide fertilizers (Castro, Araujo & Santos, 2019). Thus, the present study investigates the water quality of cisterns from communities in the semiarid region of Pernambuco state.

## Material and Methods

The experimental areas were the communities of Serra Grande, Settlement Poço do Serrote, Settlement Poldrinho and Settlement Catolé, a region of Sertão do Pajeú, semiarid environments of the State of Pernambuco. The region near the Serra da Lagartixa, belonging to the municipal boundary between the cities of Serra Talhada and Floresta, geographic coordinates of 38°23'55.51" W and 8°07'06.72" S.

The climate of the region was classified as type Bwh, called semiarid, hot and dry, with

summer and autumn rains according to the Köppen classification. The average annual rainfall for 1912 to 1991 is 647 mm year<sup>-1</sup> and annual temperature above 25°C (Sudene, 1997).

The samples were collected to analyze water quality from December 2013 to March 2014 weekly, a period considered rainy in the semiarid region of Pernambuco state. Samples were stored in 500 mL plastic containers previously washed with 0.1 mol L<sup>-1</sup> hydrochloric acid cleaning solution and distilled water. Containers were opened at the collection site, filled with water, capped, enumerated, and stored. This process was performed in each of the six plate cisterns that store only rainwater, located in the rural communities of Serra Grande, Poço do Serrote settlement, Poldrinho settlement, and Catolé settlement.

According to the order of the first collection, the cisterns were enumerated in the first week of December 2013. Geographical coordinates identified the cisterns' location with the aid of a GPS device, and the coordinates were verified with the aid of Arcview Gis software v.9.3.

The samples were sent for chemical analysis of water where electrical conductivity (C.E.), hydrogen potential (pH) were determined, and physical analyzes were determined for color, turbidity, and total dissolved solids (S.D.T.) (APHA, 2012). In the microbiological analysis, total and fecal coliforms were identified using the multiple tube technique (APHA, 2012).

The descriptive analyzes used were the maximum and minimum values, the mean, median, standard deviation, asymmetry, kurtosis, and coefficient of variation. The normality of the data was performed using the parametric tests Kolmogorov-Smirnov, Anderson Darling, and Shapiro-Wilk (Follador et al., 2012). Control charts, the Shewhart chart or individual chart, the CUSUM chart, and the Exponential Weighted Moving Average (EWMA) chart (Montgomery, 2016) were implemented.

## Results and Discussion

Table 1 shows the main descriptive measures of the variables, and they were interpreted according to the specificities of each parameter.

Table 1. Descriptive statistics of water quality variables. Font: Cunha Filho, M (2019).

Statistics	Variables				
	pH	Color uH	Turbidity UNT	S.D.T mg L <sup>-1</sup>	C.E mS cm <sup>-1</sup>
Minimum	7.35	2.76	1.01	55.96	87.44
Maximum	8.42	8.70	3.37	78.05	121.95
Average	7.83	5.75	1.88	70.12	109.57

Median	7.87	5.36	1.83	70.19	109.68
Variance	0.09	3.67	0.39	32.82	80.12
Standard deviation	0.30	1.91	0.62	5.72	8.95
Asymmetry	-0.14	0.04	0.71	-0.67	-0.67
Kurtosis	-0.93	-1.38	-0.11	0.06	0.06
Coefficient of variation (%)	3.85	33.30	33.26	8.16	8.16

pH = hydrogen potential; S.D.T. = total dissolved solids; C.E. = electrical conductivity.

The interpretation was based on the minimum, maximum, and arithmetic mean of values obtained in studied properties regarding the physical and chemical variables. The pH ranged from 7.45 to 8.42, values considered acceptable according to Brasil (2011), which considers that the water intended for human consumption has a pH between 6.0 and 9.5.

The color had a maximum value of 8.7 uH (Hazen unit), which means that it is within specifications as the maximum value stipulated by Brasil (2006) is 15 uH. Regarding turbidity, the same occurred since the maximum tolerated value is 5 uT (Turbidity units), and in the studied tanks, the maximum value measured was 3.37 uT.

Total dissolved solids (S.D.T.) averaged 70.12 mg L<sup>-1</sup>, meaning that all impurities found in water except dissolved gases contribute to total solids loads present in water bodies (Parron, Muniz & Pereira, 2011).

The variables pH, C.E., and S.D.T. presented a coefficient of less than 10% variation, which indicates a low variability of data around the mean.

The interpretation is based on the absence or presence of microorganisms, considering total and fecal coliforms, so it is necessary to study each sample individually. The maximum levels of impurities allowed in water are set, according to the uses, and should be compared with values required by Brasil (2011).

According to the present study, in 15.0% of the cisterns, the number of total coliforms remained below 3.0, and 7.0% showed values above 1,100.00, indicating that the instrument used in the measurement cannot capture well.

The highest frequency of cisterns (35.0%) has fecal coliforms less than 3.0 followed by 3.6 (27.0%). The lowest frequency (7.0%) corresponds to the most considerable quantity of fecal coliforms concentrated in the water sample (23.0). According to Rocha et al. (2010), microbiological contamination of water also has a positive relationship with the lack of maintenance and cleaning of water collection and storage systems. Therefore, the longer the period without cleaning the gutters and cisterns, the greater the possibility of this contamination. Despite the recommendation of cleaning gutters and cisterns at least once every

year, maintenance is rare, except when there is clogging in the gutters, making water storage impossible.

According to Brasil (2011), in supply systems with less than 40 samples per month, there is a tolerance of only one sample with positive results for the presence of coliforms. In the present study, with 16 samples per month, this value is higher than tolerated since at least 65% of the samples showed fecal coliforms and, in at least 85% of the samples, the presence of total coliforms was found.

Similar results were obtained by Siqueira et al. (2010), in which they identified fecal coliforms in water samples used for consumption and in feeding units. These results indicate health risks mainly for those families that do not have previous water treatment. Some measures are recommended for improving water quality; simplified treatment processes such as filtration, boiling, and chlorine application are some of them.

It was observed in the graphs for pH the individual measurements that there is a tendency of the data around the average (Figure 1). In the most change-sensitive graphs, such as the CUSUM graph (Figure 2), and EWMA graph (Figure 3), a sequence of points above the midline is noted in a timeline that corresponds from the 5th to the 10th week of the sample period.

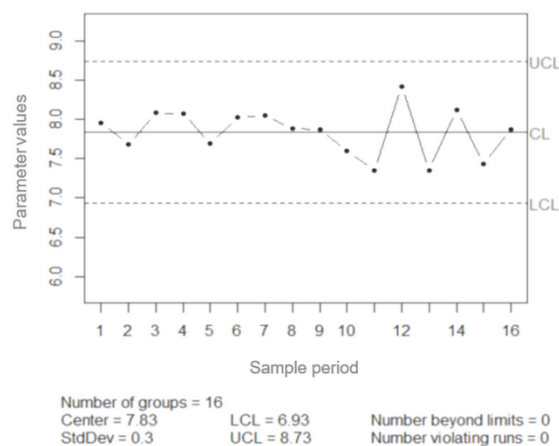


Figure 1. Values of pH by the Shewhart method. Font: Cunha Filho, M. (2019).

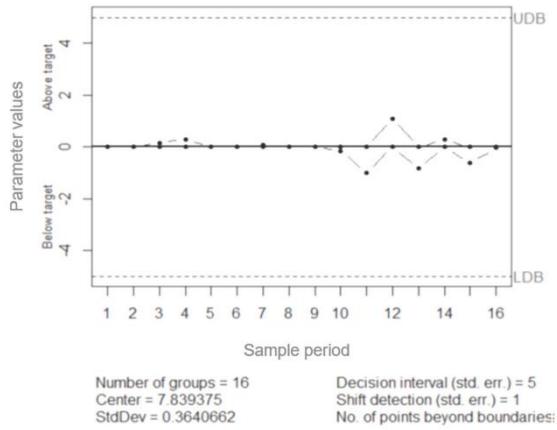


Figure 2. Values of pH by the CUSUM method.  
Font: Cunha Filho, M. (2019).

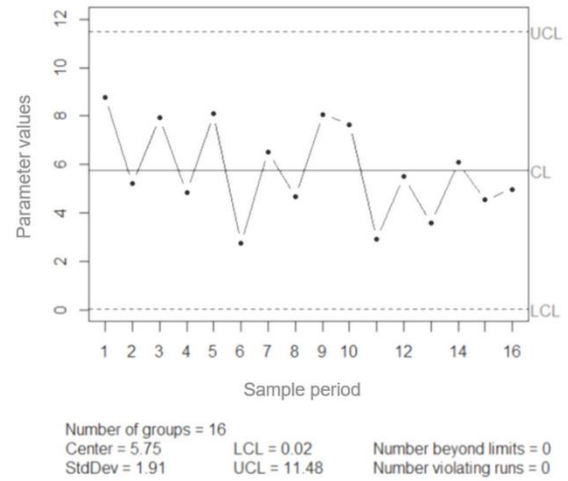


Figure 4. Values of color by the Shewhart method.  
Font: Cunha Filho, M. (2019).

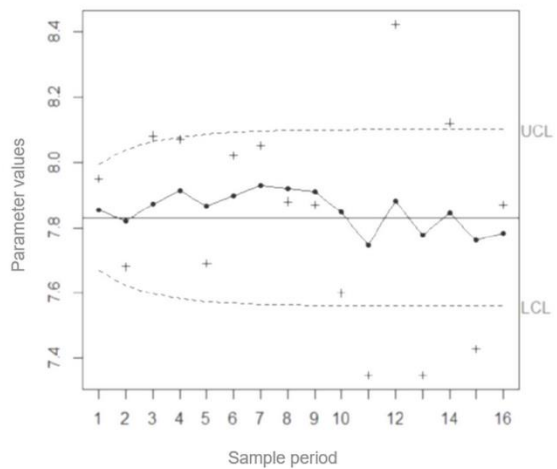


Figure 3. Values of pH by the EWMA method.  
Font: Cunha Filho, M. (2019).

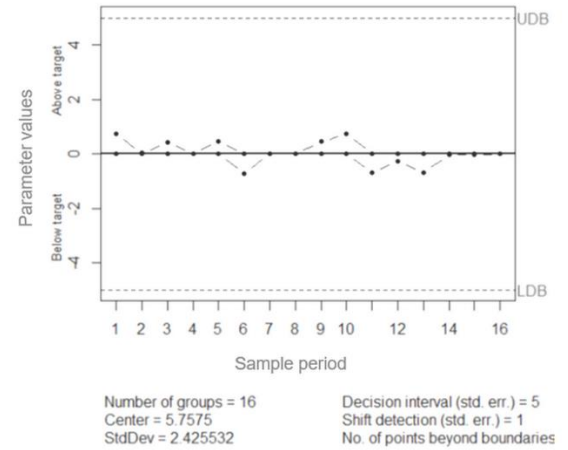


Figure 5. Values of color by the CUSUM method.  
Font: Cunha Filho, M. (2019).

The color variable in the Shewhart (Figure 4), CUSUM (Figure 5), and EWMA (Figure 6) graphs did not show sequential measurements or point to any trend in apparent color observations at 16 weeks. Morais (2016) study in the water quality assessment of cisterns in the Sergipe semiarid found similar values concerning watercolor, which states that despite the high variability of the data, the watercolor remained below the 15 uH recommended for potable water.

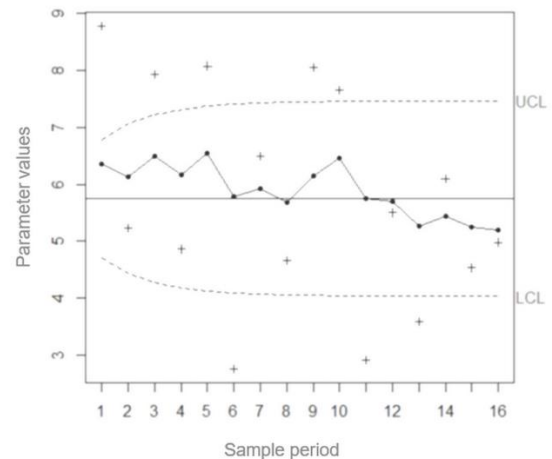


Figure 6. Values of cor by the EWMA method.  
Font: Cunha Filho, M. (2019).

Figure 7 shows the Shewhart graph for turbidity with a sudden change in the behavior of the observations. In the 15th week, the observation in the previous week was below the average line grew significantly and continues to increase the

following week. Activities such as buckets to remove water from cisterns may have caused this increase in turbidity. Al-Khatib & Arafat (2009) state that solid particles in water, when agitated, stay in suspension, increasing turbidity, taking some time to accumulate at the bottom when the water flow ceases. This statement corroborates what happened.

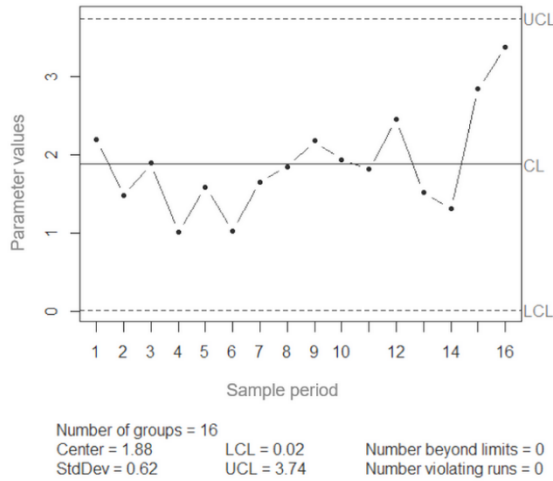


Figure 7. Values of turbidity by the Shewhart method. Font: Cunha Filho, M. (2019).

Considering Portal et al. (2019), this fact indicates suspended particulate material (sand, mud, clay) and the presence of microorganisms, which interferes with the penetration of light through diffusion and absorption. Despite not exceeding the 5 uT recommendation, it is recommended to investigate possible causes of alteration, such as using dirty buckets to remove water from the cistern.

In the CUSUM (Figure 8) and EWMA (Figure 9) control charts, the sequence of points below the midline is easily identified. According to Montgomery (2016), the sequence of seven points or more below the midline indicates that the process is out of control, and immediate investigation is recommended.

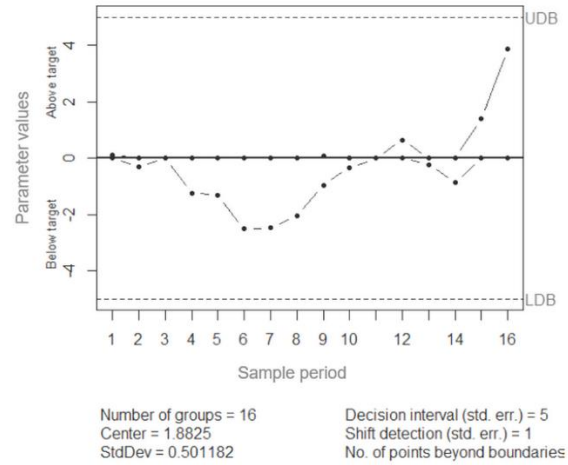


Figure 8. Values of turbidity by the CUSUM method. Font: Cunha Filho, M. (2019).

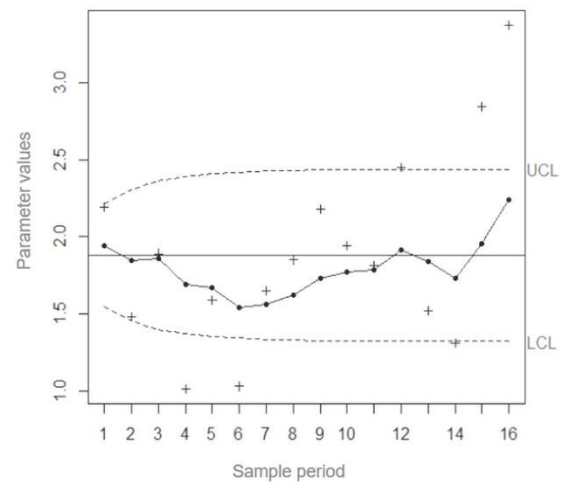


Figure 9. Values of turbidity by the EWMA method. Font: Cunha Filho, M. (2019).

The S.D.T. values did not present points indicating trends or periodicity either in the Shewhart method (Figure 10) or in the CUSUM method (Figure 11). The EWMA control chart (Figure 12) shows an upward trend from the second observation and a change in the variation pattern from the sixth observation that corresponds to the middle of January.

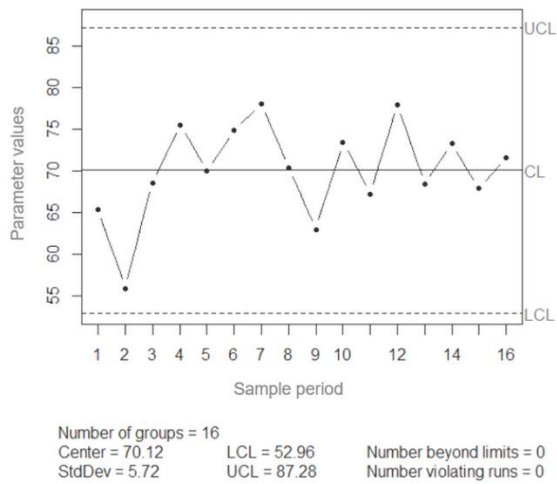


Figure 10. Values of total dissolved solids (S.D.T.) by the Shewhart method. Font: Cunha Filho, M. (2019).

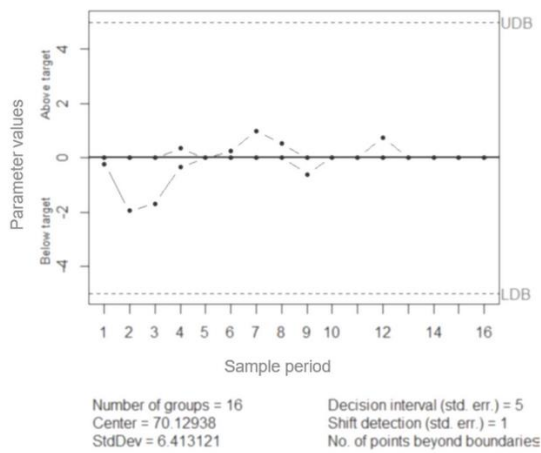


Figure 11. Values of total dissolved solids by the CUSUM method. Font: Cunha Filho, M. (2019).

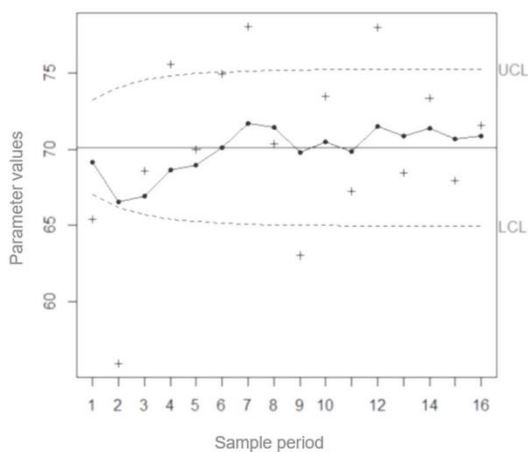


Figure 2. Values Behavior of electric conductivity by the Shewhart method. Font: Cunha Filho, M. (2019).

Although not exceeding the recommended amount of 500 mg L<sup>-1</sup>, Buzelli & Cunha-Santino (2013) report similar results to those exposed in this study in a water quality analysis and diagnosis

of a reservoir in Barra Bonita, SP showing SDT values. The authors also state that total dissolved solids' behavior resembles that of turbidity, directly related variables. Therefore, the results of S.D.T. and turbidity are coherent because they are below the maximum values.

In the statistical quality control charts (Figures 13 and 14) for C.E., there is no trend and periodicity, and observations beyond the charts' limits indicating that the process is under control are also absent. There is an upward trend in the EWMA control chart from the second observation to the seventh, which corresponds to mid-December 2013 to end-January 2014 (Figure 15).

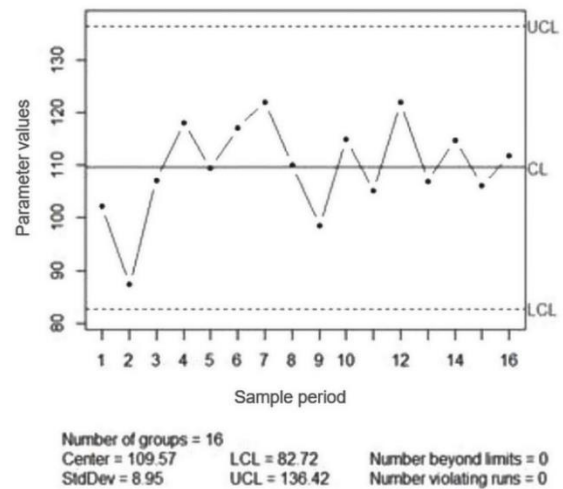


Figure 13. Values Behavior of electric conductivity by the Shewhart method. Font: Cunha Filho, M. (2019).

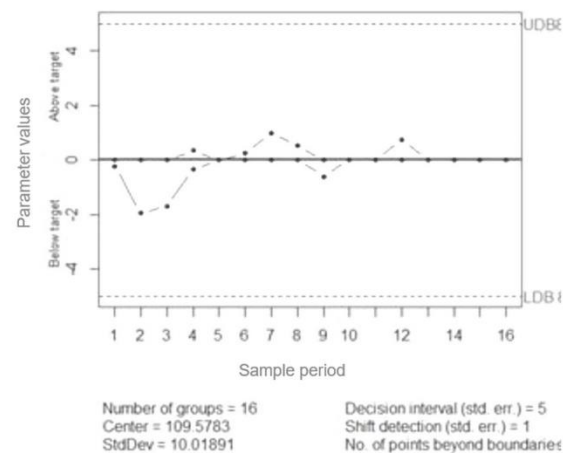


Figure 14. Values of electric conductivity (C.E.) by the CUSUM method. Font: Cunha Filho, M. (2019).

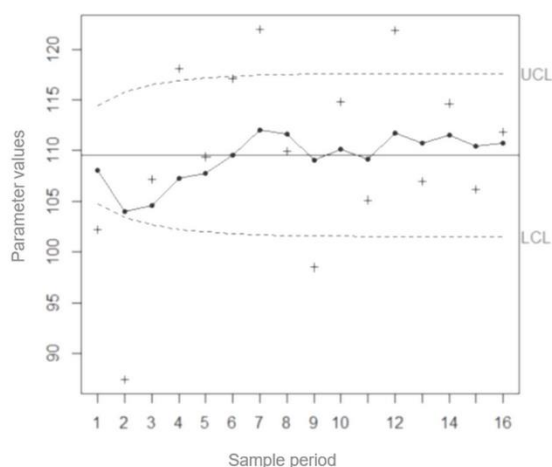


Figure 15. Values of electric conductivity (C.E) by the EWMA method. Font: Cunha Filho, M. (2019).

According to Brasil (2006), water's electrical conductivity indicates its ability to transmit electric current due to the presence of dissolved substances in anions and cations. The higher the ionic concentration of the solution, the greater the ability to conduct electric current.

### Conclusions

The only variables that did not meet the specifications were total coliforms and fecal coliforms. The most likely reason for the incidence of water contamination in cisterns by coliforms is the lack of cleanness of the gutters that are part of the water collection system and the use of dirty buckets to remove stored water. The statistical quality control graphs did not reveal anything beyond the ordinary regarding observations outside the upper and lower limits of the control charts. Only the color variable did not show any signs of abnormality in the process, but when the capacity indices were calculated, an alert appeared, requiring an investigation about the process's variability.

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