TABULAR CUSUM CONTROL CHARTS OF CHEMICAL VARIABLES APPLIED TO THE CONTROL OF SURFACE WATER QUALITY

FRANCIELE A. C. FOLLADOR[1], MÁRCIO A. VILAS BOAS[2], MARLISE SCHOENHALS[3], ELIANE HERMES[4], CLOVIS RECH[5]

ABSTRACT: The aim of this study was to evaluate the application possibility of tabular CUSUM control charts in the quality control of chemical variables in surface water. It was performed bibliographic and field research to collect water samples from 2003 to 2009, totaling 30 samples, some monthly and others semi-annual in order to observe the variables that regulate water quality. It was found that these charts may be applied to control the quality of river water; showing to be effective in the perception of changes during the process, especially for small samples (n=1) which there is no repetition as in this research. It was also concluded that the Mandurim River does not presents significant levels of pollution.

KEYWORDS: environmental planning, control charts, water quality.

CARTAS DE CONTROLE CUSUM TABULAR DE VARIÁVEIS QUÍMICAS APLICADAS AO CONTROLE DE QUALIDADE DE ÁGUAS SUPERFICIAIS

RESUMO: O objetivo do trabalho foi avaliar a possibilidade de aplicação das cartas de controle do tipo CUSUM tabular no controle de qualidade de variáveis químicas em água superficial. Foi realizada pesquisa bibliográfica e de campo com coleta de amostras de água, no período de 2003 até 2009, perfazendo 30 coletas, algumas mensais e outras semestrais, com o intuito de observar as variáveis que regulam a qualidade da água. Verificou-se que estas cartas podem ser aplicadas ao controle de qualidade de água de rio, mostrando ser eficazes na percepção de alterações durante o processo, principalmente para amostras pequenas (n=1), para as quais não há repetição, como é o caso desta pesquisa. Também se concluiu que o Rio Mandurim não apresenta poluição em níveis consideráveis.

PALAVRAS-CHAVE: planejamento ambiental, cartas de controle, qualidade da água.

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[1] Graduada em Química, Doutora em Engª Agrícola (Recursos Hídricos e Saneamento Ambiental), Membro do PLANAMB - Grupo de pesquisa em planejamento ambiental no Sudoeste do Paraná, Professora da Unioeste -Universidade Estadual do Oeste do Paraná.

[2] Dr. em Agronomia, Prof. Associado C da Unioeste, Membro do RHESA (Grupo de Pesquisa em Recursos Hídricos e Saneamento Ambiental).

[3] Técnologa Ambiental, Mestre em Engª Química, Membro do PLANAMB, Prof. da UTFPR (Univ. Tecnológica Federal do Paraná).

[4] Graduada em Química e Tecnologia Ambiental, Mestrado em Engª Agrícola (Recursos Hídricos e Saneamento Ambiental), Doutoranda em Engª Agrícola (Recursos Hídricos e Saneamento Ambiental) e Prof. da UFPR (Univ. Federal do Paraná).

[5] Geográfo. Mestre em Engª Agrícola (Recursos Hídricos e Saneamento Ambiental), Professor SEED e Técnico do IAP.

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INTRODUCTION

The growth of the agricultural areas and consequently deforestation has affected water resources and quality of life of the population, requiring a reorganization of space and especially the management of natural resources (VALLE JÚNIOR et al., 2010).

Associated to this, the increase of pollution sources such as industrial and household waste has contributed to the decrease in water availability due to the degradation of the ecosystems (BRITO et al., 2006). The pollution of rivers is already detected in over 30% of Brazilian cities (KAHRAMAN & KAYA, 2009; BRITTO & RANGEL, 2008).

The physical, chemical and biological processes that characterize water quality endure large variations in time and space, and there is a need for a systematic monitoring program for a real estimate of the variation of surface water quality (SIMEONOV et al., 2003).

The techniques of statistical control help develop charts to evaluate the environmental performance and analyze data. Several types of statistical analysis may be used, among them there is the individual control chart, the EWMA chart (exponentially weighted moving average) and the CUSUM chart (cumulative sum) which is one of the instruments for monitoring and evaluating the emissions data and abnormal changes of the environment (CORBETT & PAN, 2002). The cumulative sum charts are viable alternatives to the Shewhart control charts, because they store accumulated information from the entire sequence of points and therefore are more sensitive to detect small deviations from the mean of a process.

The techniques of process statistical control are used for a long time, but not to control the quality of surface water, observing the originality of the proposal. In the process control is essential to have simple mechanisms to quickly indicate the occurrence of events that results in an uncontrolled process, the CUSUM chart shows this profile.

The aim of this study was to control statistically and evaluate the water quality of the Mandurim River located in Marmeleiro city - State of Paraná (PR), Brazil, via tabular CUSUM control chart. This river is classified as class two; it has along its course pig farming activity, and water samples were collected through 6 years, at monthly intervals from 2003 to 2005 and semi-annual in the rest of the period.

MATERIAL AND METHODS

The Marrecas River basin, which is part of the Mandurim River, has an approximate area of 90,000 hectares (836.50 km^2), representing 4.8% of the Southwest region of Paraná; the Rio Marrecas is the main river of the basin and has an extension of 110.6 km. The micro-basin of the Mandurim River has an area of approximately 22.4 km². The length of the main axis of the river Mandurim has approximately 9.5 km and is located in the city of Marmeleiro-PR.

The drainage area of the micro-basin of the Mandurim River is approximately 2,269 ha of land, and there are about 20 pig farmers, micro and small producers, living in a household system, with low technological level, diversification of activities, from farming to animal breeding. The soils of the micro-basin region are mostly well developed (progressive differentiation of horizons), but the undulating relief makes them susceptible to surface erosion and the process of percolation of water inside, requiring management processes suitable for agricultural use (RECH et al., 2008).

The area of the micro-basin of the Mandurim River presents altitude between the 550 and 820 m quotas, with an incident area of approximately 186 ha, corresponding to a percentage of 8% of the total of the micro-basin, between the altitudes of 550-600 m, which remains covered mostly by vegetation and pasture, and the agriculture is undeveloped in this area. In intermediate quotas (600 to 800 m) comprehending 90% of the basin area is predominant the tillage, while the quotas above 800 m, are permanent preservation areas (RECH et al., 2008).

To evaluate the water quality of this river, it was used two points, the 1st point located upstream, near the headwaters of the river in the geographical coordinates of Latitude: 26º11'11" South and Longitude: 53º06'01" West, and altitude of 637 m. The 2nd point located downstream near the river Mandurim in the geographic coordinates of Latitude: 26º08'03" South and Longitude: 53º06'08" West, and altitude of 563 m (RECH et al., 2008). The collection of water samples occurred from 2003 to 2009, totaling 30 collections at the two points. The parameters chosen for evaluation of water quality were: total phosphorus, pH, total nitrogen, dissolved oxygen, oxygen biochemical demand (OBD), and oxygen chemical demand (OCD). The methods for determining the parameters are described in Standard Methods for the Examination of Water and Wastewater (1992).

To construct the CUSUM chart, the Anderson-Darling, Ryan-Joiner and Kolmogorov-Smirnov test was performed to characterize the normality of the data and the autocorrelation test, which are essential conditions for the use of control charts, because when these characteristics are not attended the results may be misleading (MONTGOMERY, 2004).

For the measured data that did not follow a normal distribution, we applied the Box-Cox transformation to the search of the data normality. For those that all the same not become normal, it was applied the temporal series model, the ARIMA (autoregressive integrated moving average) model, and the data of the residue were used to the execution of the graphs.

The CUSUM chart was run through the MINITAB 15 program. In this graph, as the samples are taken, the deviations of X compared to the target value μ (or average value in control) are accumulated, generating eq.(1):

$$S = \Sigma^{i}_{j=1}(X_j - \mu) \quad (1)$$

in which,

X - average of the jth sample of size n≥1.

While the process average remains adjusted to the target, the positive deviations (X>μ) will be compensate by the negative (X<μ), and the equation will oscillate randomly around the zero value. If the process average increase (or decrease), the S will increase (or decrease) indefinitely. The CUSUM chart is a plane of control of bilateral symmetrical intervallic decision that uses superior (+) Ci^+ and inferior (-) Ci^- plans to detect changes, according to eqs.(2) and (3).

$$C_i^+ = máx[0, x_i - (\mu_0 + K) + C_{i-1}^+] \quad (2)$$

$$C_i^- = máx[0, (\mu_0 - K) - x_i + C_{i-1}^-] \quad (3)$$

in which,

C - zero;

Xi - i time observation;

μ_0 - sample average;

k - compensation value, between the desired average and the obtained one.

The H decision interval used in this study used the value of 4σ. For the k it was used the value of 0.5 (magnitude of change) and the value of the sequence length was equal to 2, as suggested by the software used and the authors MONTGOMERY (2004) and NEZHAD & NIAKI (2010).

The CUSUM chart is divided in two regions, action and control, through the superior and inferior limits. The limits are of the same magnitude, the superior is positive and the inferior is negative. When the value of S exceeds one of the two limits, it is understood as a sign that the process average has shifted from the value μ. The CUSUM chart in addition to signal the misfit, informs when this occurred (MONTGOMERY, 2004).

In the charts of this study, the statistic generated and represented by the symbol (●), relates to values that squares within the interval of the superior control limit. The symbol (♦) is related to values within the inferior control limit. The symbol (■) and (▲) are values that are above or below, respectively, of the superior and inferior control.

RESULTS AND DISCUSSION

The statistical analysis of the data is presented in Table 1.

TABLE 1. Descriptive statistics of the data collected at two sampling points along the river.

Parameters	Points	Average	Standard Deviation	Coefficient of Variation (%)	Minimum	Maximum
pH	Point 1	7.27	0.33	4.53	6.26	8.00
	Point 2	7.34	0.41	5.61	6.44	8.30
Nitrogen (mgL^{-1})	Point 1	0.294	0.277	94.13	0.02	1.12
	Point 2	0.288	0.283	98.39	0.00	1.23
Phosphorus (mgL^{-1})	Point 1	0.064	0.053	83.51	0.00	0.190
	Point 2	0.063	0.046	73.66	0.00	0.170
OBD (mgL^{-1})	Point 1	3.08	3.26	105.97	0.10	12.90
	Point 2	4.54	5.83	128.48	0.10	29.60
OCD (mgL^{-1})	Point 1	9.92	10.01	100.91	0.92	36.36
	Point 2	10.07	8.66	86.05	1.10	36.20
DO (mgL^{-1})	Point 1	7.71	1.26	16.36	5.30	10.50
	Point 2	7.77	1.21	15.61	5.40	9.90

The CUSUM charts for the pH parameter at points 1 and 2 are presented in Figure 1.

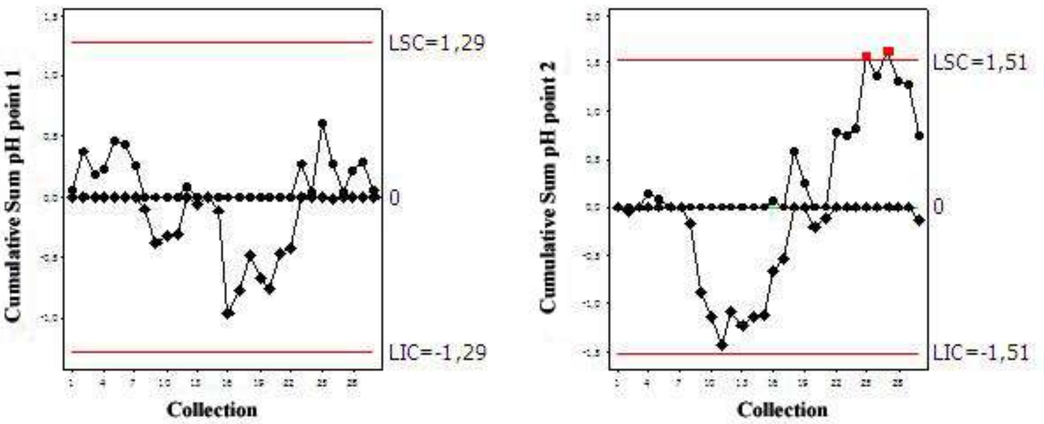

FIGURE 1. CUSUM charts for the pH parameter at points 1 and 2 of Mandurim River

According to SIMEONOV et al. (2003), in experiment observing the water quality, the parameter pH was constant at practically all points (ranging approximately between 6 and 9). In this study it is clear that the values of the samples did not vary significantly when compared with the average of the variable, having similar results to the research of the authors cited ranging from 6.2 to 8.

In studies conducted by SANCHEZ et al. (2006) about river water quality, pH values were found to range from 7.1 to 7.3. GUEVARA et al. (2006) found a mean pH values ranging between 7.2 and 7.8, obtaining just a sample which resulted in 5.1 due to the presence of dissolved metals in water. Similar results were also obtained by BORDALO et al. (2001), where pH values were close to those obtained in this study indicating that the pH of the water is especially suitable for the presence of metabolism and photosynthetic organisms.

It is possible to see on the pH chart of point 2 that two points are out of the superior H interval which is the interval that starts from the zero line towards the superior limit. This fact is observed only in the CUSUM charts, not being noticeable in individual charts (another and simpler type of control chart), which indicates that the process may be considered out of statistical control (NEZHAD & NIAKI, 2010). These values were discrepant in relation to others considering the cumulative sum, although environmentally values obtained are not an indication of problems because they are within the range (6 to 9) established in the 357/05 principle of CONAMA (Environment National Council of Brazil).

The process is in control when the values are close to zero. If moving up or down, then values will occur more positive or negative, tending to detect special causes (RIBEIRO JUNIOR & GONÇALVEZ, 2009), as shown in the CUSUM charts at point 1, where between points 1 to 6 and points 11 to 21 and at point 2 between points 2 and 8. Such situations can occur due to registry errors of the data, calculations of measurement, laboratory instruments not calibrated, equipment operator error or error in the use of the technique and defects in laboratory equipment (NOMELINI et al., 2009).

CUSUM charts for Nitrogen parameter at points 1 and 2 monitored in the river through the 30 collections from the period 2003 to 2009 are shown in Figure 2.

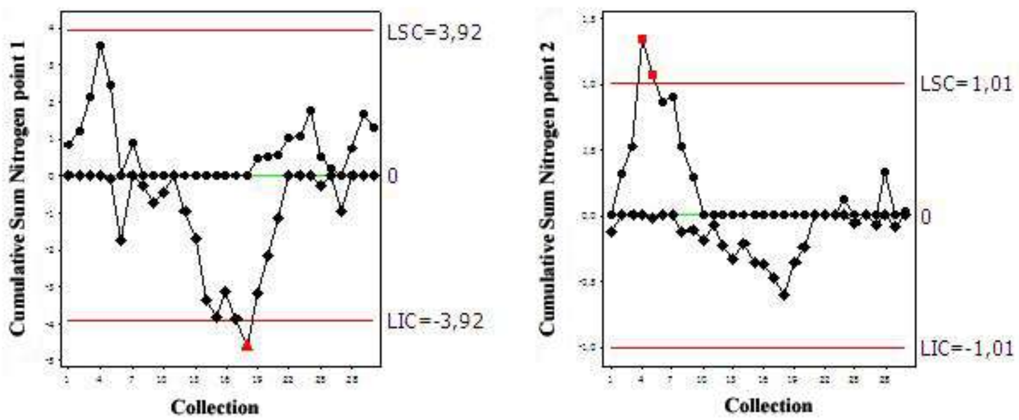

FIGURE 2. CUSUM charts for the total nitrogen parameter at points 1 and 2 of Mandurim River.

In the case of CUSUM charts, if there is a tendency of the points to place themselves above or below is evidence that the process average changed and must determine the cause attributable to this fact (MONTGOMERY, 2004). This is observed at some points in the graphs of Figure 2 where points above and below the zero line occur.

The data of total N did not presented normality, rejecting the null hypothesis of normality considering 5% of significance. To this they were transformed and the p-value for nitrogen at point 1 is 0.091 and at point 2 is 0.052.

In the study by SANCHEZ et al. (2006), in the Guadarrama River it was observed that the nitrogen parameter in its ammonia, nitrate and nitrite forms, presented in higher concentrations at the first sampling points (15.9 and 15.1 mg L^{-1} in the case of nitrate), with a slight decrease at the following points. In this study the initial values of total nitrogen were higher (0.63, 1.12 mg L^{-1}) in the first two samples, showing variation along the collections, mainly at point 1.

According to CHANG (2008), in his research on the Han basin in Korea the total nitrogen parameter showed higher concentrations (0.22 to 0.88 mg L^{-1}) along the course of the river, differently of what was observed in this research in relation to the total nitrogen parameter that showed higher concentrations in the early collections, which can be attributed to this cause the dunghills facilities very close to the river, especially at point 1, it has been verified with in loco visits, but over the period of development of the study, due to advances in technology and materials that occurred, there was a decrease of values of this parameter.

Another factor that may explain the decrease in nitrogen parameter values along the course of the river is that a dilution of the concentration of this parameter occurred.

CUSUM charts for the total phosphorus parameter at points 1 and 2 are presented in Figure 3.

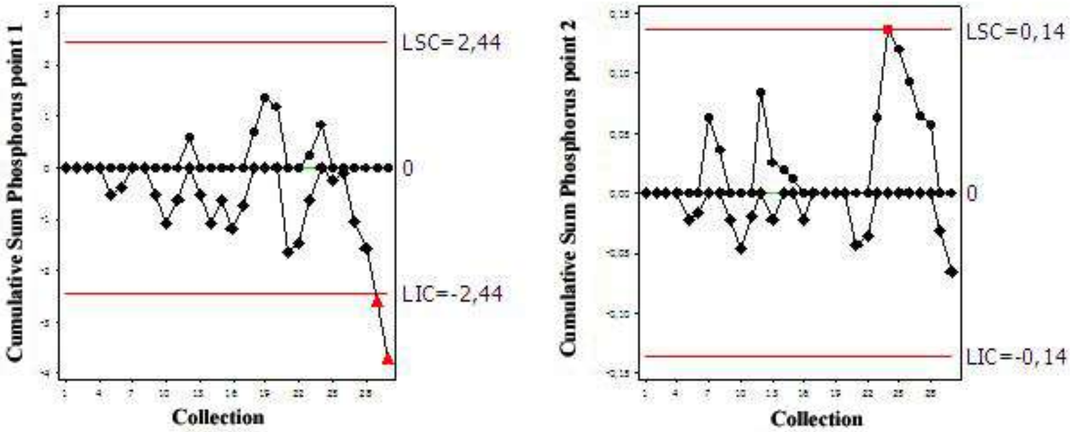

FIGURE 3. CUSUM charts for the phosphorus parameter at points 1 and 2 of Mandurim River.

In Mandurim River until the year 2006 was noted the contribution of nutrients like phosphorus, but with the implementation of protective fences and the implementation of riparian forest this landscape has been significantly modified in the local, although it may be observed for some samples, values as 0.19 mg L^{-1}, which do not fit the environmental quality principles as in Resolution 357/2005 of CONAMA, which provides values for this parameter that can vary, with up to 0.030 mg L^{-1} in lentic environments or up to 0.050 mg L^{-1} in intermediate environments. BORDALO et al. (2001) found average values for the total phosphorus parameter of 0.62 mg L^{-1} in rainy season and of 0.33 mg L^{-1} in dry season, values much higher than those found in this study that ranged from 0 to 0.19 mg L^{-1}.

CHANG (2008) in his research found values for the total phosphorus parameter lower at the first collection points and increasing variation along the river, justifying the urban population growth along the river and diffuse pollution originating from agriculture as being possible causes. Behavior data similar to the obtained in this study, which were also found lower amounts of phosphorus at the first points and variation along the river.

The CUSUM control chart for OBD at points 1 and 2 of the river are presented in Figure 4.

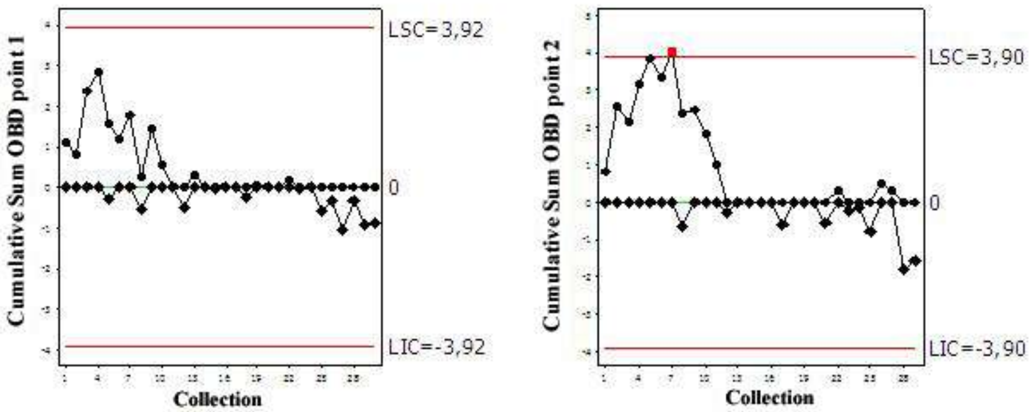

FIGURE 4. CUSUM charts for the OBD parameter at points 1 and 2 of Mandurim River.

Observing the p-value, it is possible to notice that the data generated from the field research are not normal, requiring transformation (Box-Cox). In the chart at point 2 was required the application of temporal series (ARIMA) to build the control charts, also because of the correlations between the data.

The average OBD in SANCHEZ et al. (2006) studies decreased at point 2, and the minimum value was observed at the point of discharge into the river Guadarrama probably due to oxidation of organic matter that causes the reduction of dissolved oxygen and increased oxygen deficit. Furthermore, the OBD also decreased considerably from 593 to 37 mg L^{-1} and 209 to 3 mg L^{-1}, respectively, showing that a high rate of oxidation of the organic matter was from point 1 to point 2. The values of OBD of the Mandurim River were lower (0.1 to 12.9 at point 1 and 0.1 to 29.3 at point 2) than those found by SANCHEZ et al. (2006), but had similar statistical behavior in the variation of the data. In the point 2 chart it was noticed changes in the values relative to the zero line (between samples 1 and 15) and a sample above to the superior limit (sample 7), but at point 1 no statistical value exceeded the limits proposed in the chart, being the process under control.

CUSUM charts for the OCD parameter at points 1 and 2 of the river are shown in Figure 5.

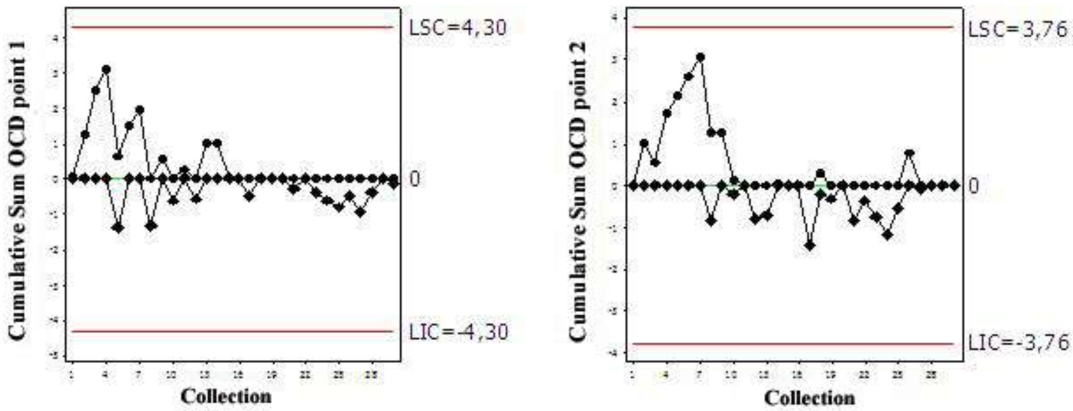

FIGURE 5. CUSUM charts for the OCD parameter at points 1 and 2 of Mandurim River.

It is possible to observe some of the initial points in the CUSUM chart for OCD at points 1 and 2, samples with values distant from the midline, indicating lack of control in the process (NOMELINI et al., 2009).

HADLICH & SCHEIBE (2007) monitoring the physical and chemical quality in Braço do Norte city - State of Santa Catarina (SC), Brazil, had averages ranging from 22; 5 and 38.4 mg L^{-1} at four points along the Coruja-Bonito River. The average value of OCD in this study was 12.02 mg L^{-1} with a maximum value of 42.69 mg L^{-1} at point 1 and an average value of 10.69 mg L^{-1} with a maximum value of 36.31 mg L^{-1} at point 2. The values were similar to those presented in this study, given that in both experiments there is intense breeding of pigs, which may contribute to the increased concentration of organic matter in the course of water, due to the inappropriate release of waste from this activity.

CUSUM charts for parameter DO at points 1 and 2 of Mandurim River are shown in Figure 6.

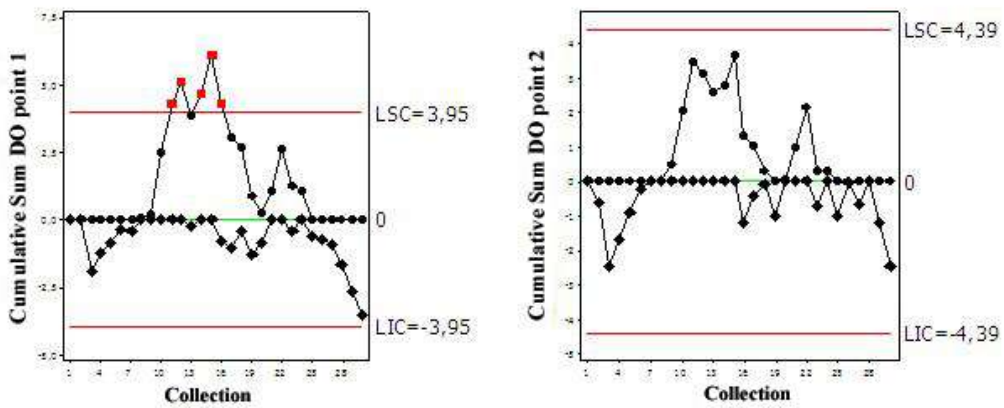

FIGURE 6. CUSUM charts for the DO parameter at points 1 and 2 of Mandurim River.

The results of SANCHEZ et al. (2006) suggested that the oxygen was a representative parameter to establish a relative scale to the water quality. The authors, in their research, found dissolved oxygen values between 3.6 and 4.4 mg L^{-1}.

According to the article 15, clause VI of the Resolution 357/05 of CONAMA for class 2 waters, the minimum value of DO in any sample must not be inferior than 5mgL^{-1} (BRAZIL, 2005). In this study we found values between 5.4 and 10.5 mg L^{-1}, thus agreeing with the Resolution 357/05 of CONAMA. Environmentally, this is favorable and may be due to temperature, because at lower temperatures the concentration of dissolved oxygen in the water is greater. Statistically, some plotted values are observed in Figure 6 (point 1) which is above the superior limit, possibly making the process out of control.

From the sample 25 occurs the beginning of a sequence of below average samples, which could indicate that the process may have undergone some change and being under the influence of special causes fitting to investigate the cause of this instability in the process (could be equipment error, analyst error, lack of sample repetition, among other factors) indicating the need for promotion of corrective actions in order to return to stability. It presents a sequence from the second through the tenth sample, since the points are below the midline (NOMELINI et al., 2009).

In Figure 6 at point 2 occurs from the sample 9 a sequence of 10 points, all on the same side of the midline, indicating instability in the process (CORBETT & PAN, 2002). ALENCAR et al. (2004) in their studies found similar results, noting sequential points, characterizing non-randomness of the data. For these authors who used the Shewhart and CUSUM charts in their studies, monitoring environmental variables, these charts are more effective in the detection of changes in the process.

ZHOU et al. (2007) used Shewhart and CUSUM control charts and then correlated them by monitoring the water quality. The study resulted in the combination of control charts realizing the importance of its use for the study of control processes. It also discusses that in order to monitor a fountainhead and be successful in the interpretation of the data the statistical analysis is needed to have a global understanding of the system, as was done in this research.

CONCLUSIONS

The quality of Mandurim River water do not presents pollution in worrying proportions for the analyzed parameters, but is observed in relation to the statistical control, some points out of the specified patterns by the control limits and the present legislation.

The CUSUM tabular charts showed up as a dynamic methodology to efficiently monitor the quality of a process, in this study the water quality of the river.

The CUSUM charts showed that for the variables of pH, total nitrogen and OBD at point 2, and DO and total phosphorus at point 1, the processes proved to be out of statistical control by presenting more than two samples above or below the limits of the chart, indicating the presence of special causes, which may be related to errors in collection or errors of the operator or discharge of waste next to the collection.

We suggest that new researches on the use of the techniques of statistical quality control, for monitoring the water quality are realized in order to implement this technique for this purpose, considering that this application are still restricted in this area.

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