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Applicability of statistical tools for evaluation of water treatment plants

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ABSTRACT

This paper aims to demonstrate the use of some statistical tools to evaluate the performance of water treatment plants (WTP) in terms of water quality effluent. On such a purpose, mean values of daily recorded data on raw water and treated water quality were accounted within the period between 2001 and 2011 at six WTP of which average inflow rate varied from 0.033 to 4.4 $m^3 s^{-1}$. In order to evaluate the seasonality effect on the raw water quality and the performance of such plants, the results found during the wet and dry season were set apart. The results pointed out the feasibility of these statistical tools, and considering the effluent turbidity as the main parameter, the statistical analysis showed that performance level of the plants is not dependent on their sizes or raw water quality. Additionally, all plants evaluated had their performance reduced during the wet season compared to the dry season.

Keywords: Performance evaluation; Statistical analysis; Reliability analysis; Water treatment

1. Introduction and relevance

The performance of the water treatment plants (WTP) depends on several factors such as raw water quality, suitable chemical products dose, hydraulic parameters of each individual treatment steps, operational staff commitment to the ultimate goal, and treated water quality. The performance evaluation may be accomplished by taking into account the efficiency of each treatment step as a process, and also by only taking an account of the plant influent and effluent at system level. The first approach has been the most adopted one for water treatment plant control, while the global analysis has been the alternative most adopted by regulatory agencies.

To attain proper water treatment plant performance, three requirements must be met, that is to say, robustness, reliability, and resiliency. The first one is important to ensure effluent quality independently on the variation of raw water quality over dry and wet seasons; reliability, which is related to the probability of meeting the drinking water quality standards within a defined time frame, or the water quality standard set by the plant operation staff

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itself, or by a regulatory agency. At last, resiliency represents the time required by the water treatment plant to restart producing high-quality effluent after the occurrence of any system failure such as, for example, coagulant addition interruption [1].

In such a context, it may become necessary to utilize other methods to evaluate water plant performance that prove to be adequate to evaluate features other than drinking water quality only, but also check the quality standards mentioned above, and even encompass physical, financial, and human resources to produce high-quality drinking water.

Using simple statistical tools and filtered water turbidity as treatment efficiency parameter and as an indicator of protozoan cysts and oocysts removal, an extensive study was carried out at 75 plants in the state of Pennsylvania, USA. Based on the average of the data collected monthly over 10-year plant operation period, the evaluation was focused on the following parameters: size of the population supplied, filtration rate, type of filter media, type of water source, water treatment process, application and type of coagulant, and plant age. The statistical study showed that 95% of the annual averages and maximum monthly turbidity values remained under 0.2 and 0.3 NTU, respectively. The conclusion was that factors usually being considered as more relevant for plant performance, such as raw water quality and hydraulic parameters, may have the same relevancy when compared to intangible factors such as proper operation and operational staff commitment to the goal of producing the highest quality water [2].

The use of more effective statistical methods to set water quality standards is the most realistic and practical approach from the operational point of view. An example is the limit for effluent turbidity after filtration process set by Brazilian drinking water quality standards, established by Regulation 2914 [3]. This Regulation 2914 defines maximum values of effluent turbidity (0.5 NTU), followed by their respective compliance rate, and progressive targets, which has been in effect since December, 2012. In this context, in December, 2015, 95% of samples of effluent turbidity must be lower than 0.5 NTU, focusing on protozoa cysts and oocysts removal.

The limits set together with compliance rates require detailed information on the behavior regarding the parameters being considered. The plants must be planned in a way to handle an expected variety of effluent characteristics so that the goals will comply with the required efficiency ratio. In such a context, the reliability analysis emerges as a proper tool to evaluate both, limits and the efficiency ratios from basic statistic data representing the effluent quality monitoring procedures [4].

As a concept similar to the one mentioned above, reliability may be understood as a time frame in which the plant effluent quality complies with the preset drinking water quality standards [5,6]. Assuming that the parameter samplings are regularly done at short intervals, just enough to collect data to ensure the representativeness of the process, it is possible to conclude that percentage of samples that comply with the standard is equivalent to the time frame within which the operation was acceptable, and so the reliability of the aspect being evaluated.

Therefore, the general purpose of this work consists in statistically evaluating the performance (in terms of effluent quality) of six WTP of different sizes and using different technologies based on secondary data. Additionally, statistics assess the influence of seasonality, plant size, and raw water quality regarding effluent turbidity magnitude.

2. Methods

2.1. Initial considerations

At a first moment, data records related to raw and treated water quality were collected at six WTP operated by the same concessionary in the Central West region of Brazil. The plants supply water to a population of about 2.5 million people spread over an area of nearly 5,800 km^2 with an annual average precipitation of about 1,750 mm.

The available data related to the water quality considered daily average records of turbidity, apparent color, free chlorine and fluoride concentrations, alkalinity, pH, and total coliforms between 2001 and 2011.

After the data collection used to evaluate the seasonality effects on the raw water quality and plant performance, the data recorded at the same period of time from 99 pluviometric stations in the same region was then used. Based on the precipitation records taken on the day being studied, every data entry was examined individually, and if precipitations were concurrently recorded at three or more stations, such day was considered to be a wet day. So, the data records related to dry and wet periods were set apart for preliminary statistical analysis.

After preliminary statistical analysis, the data were submitted for further statistical analyses. Besides treated water quality requirements and the ranges set for Brazilian drinking water quality standards, the results of such analyses were based on the evaluation of raw water quality regarding water source type and plant size. Finally, a reliability analysis of each plant was carried out.

2.2. Description of the WTP

As mentioned above, the study was focused on evaluating the performance of six WTP of which main characteristics are shown in Table 1.

The difference between the sizes was based on the inflow rate magnitude. Plants with average inflow rate below 0.090 $m^3 s^{-1}$ and able to supply a population upto 35,000 people (based on average water per capita consumption in the region) were considered to be small; plants with capacity to produce drinking water between 0.091 and 1.0 $m^3 s^{-1}$ were considered to be medium (supplied population up to 300,000 people); while inflow rate higher than 1.0 $m^3 s^{-1}$ were considered as large.

2.3. Data analysis

The preliminary statistical data analysis consisted of identifying extreme deviation from the mean values (outliers), inconsistent values, or even data input errors. To identify the outliers, IQR (Interquartile Range) was used to calculate the difference from the third quartile (Q75) to the first quartile (Q25), that is, upper outlier was every value above (Q75 + 1.5IQR), while lower outlier was every value below (Q25 − 1.5IQR) [7].

The search for the presence of outliers was restricted to the parameters of free chlorine, fluoride, and pH. The presence of outliers for turbidity and apparent color of raw and treated water was not evaluated as they may be affected by rain events, and/or plant performance. In such way, these records may result in extreme values, which are usually seasonal and not significant. The parameter related to the presence of total coliforms was monitored at only three plants, thus not evaluated at the present stage due to insufficient data availability.

In descriptive statistic, the calculation comprised the number of data records available, average, median, minimum, maximum, the 10, 25, 75, and 90% percentiles, standard deviation, and coefficient of variation (CV). In the second stage, the normality was checked using the Shapiro–Wilk test and a graphical technique, namely normal probability plot using the statistic software named Statistica 6.1.

Later on, the records related to alkalinity and pH were excluded from data analyses. The first parameter was not mentioned as it had no sanitation significance related to drinking water quality standards. Regarding pH, such decision was due to its higher uniformity degree in the results and significant amplitude of this chemical characteristic in the recommendations mentioned in the Regulation 2914 [3] (6.0–9.5 in the distribution system). It s worth mentioning that the monitoring of the parameters evaluated was performed according to the recommendation of the standard methods [8].

After the preliminary statistical analysis, statistic tests of nonparametric hypotheses that analyses multiple independent samples were carried out (Kruskal–Wallis followed by multiple comparison test) in order to:

(1) Check whether raw water quality parameters were significantly different from one water source from another, regarding their turbidity and apparent color;
(2) Evaluate the performance of the plants regarding seasonality and size, initially from turbidity and apparent color, and residual chlorine and fluoride concentrations.

Table 1
Characteristics of the six water treatment plants included in the sampling procedures

Water treatment plant	Treatment process	Average inflow rate in 2011 ($m^3 s^{-1}$)	Average filtration rate ($m^3 m^{-2} d^{-1}$)	Plant size	Water source type	Startup year
I	Conventional[a]	1.79		Large	Lentic	1959[b]
II	Conventional	0.093	203	Medium	Lotic	1994
III	Conventional	0.033	198	Small	Lotic	1990
IV	Conventional	0.032	244	Small	Lotic	1996
V	Direct filtration with flocculation	4.4	274	Large	Lentic	1986[c]
VI	Double filtration	0.320	194/290[d]	Medium	Lotic	2000

[a]Water treatment process comprising rapid mix, flocculation, sedimentation, filtration, and disinfection.
[b]This plant was rebuilt in 2006 and had its treatment process changed from direct filtration to conventional treatment featuring a flocculation unit.
[c]It was rebuilt in 1996 with no change in its treatment process.
[d]Filtration rate of upflow and downflow filters, respectively.

At last, a reliability analysis of the treated water turbidity was carried out, considering the expected compliance with the drinking water quality standards set by the mentioned Regulation 2914 [3] and the United States Environment Protection Agency [9]. The application of reliability analysis is basically aimed at consistency of the data related to effluent quality parameters to the lognormal distribution as the methodology developed and described by Niku et al. [5] includes properties inherent to such distribution. Thus, it is possible to determine the coefficient of reliability (COR) that relates the records of the parameter of interest of the effluent to the limits set by drinking water quality standards in probabilistic basis.

For such a purpose, the mean value required for the control parameter (X_{mea}) is obtained by Eq. (1):

$$X_{mea} = COR \cdot X_{max} \quad (1)$$

In which:

X_{max}: quality target level or standard set by law or norm.

The above-mentioned COR may be determined by the Eq. (2):

$$COR = \left(\sqrt{CV^2 + 1}\right) \cdot \exp\left[-Z_{1-\alpha}\sqrt{\ln(CV^2 + 1)}\right] \quad (2)$$

In which:

CV: coefficient of variation (standard deviation divided by mean);

$Z_{1\text{-}\alpha}$: standardized normal variable (obtained from the standard normal variate tables[1]) corresponding to the probability not to conform to the drinking water quality standards. It takes the values of 2.326 (α = 99%), 1.645 (α = 95%), 1.282 (α = 90%), 0.842 (α = 80%), 0.525 (α = 70%), 0.253 (α = 60%), and zero (α = 50%).

For example, the water treatment plant of which effluent turbidity records present CV of 0.53 so that this parameter is below 0.5 NTU over 95% of the operating time, according to the recommendation of the mentioned Brazilian drinking water quality standard, the effluent average turbidity must be up to 0.25 NTU. To comply with USEPA standard over 95% of the operating time, the plant should attain an effluent turbidity average up to 0.15 NTU.

The second stage of the performance evaluation may be attained by reversing the procedure. Based on the mean values found (X_{mea}) and the CV observed (COR_{Obs}), the compliance rate expected may be determined by Eqs. (3) and (4) [5].

$$COR = X_{mea}/X_{Obs} \quad (3)$$

In which X_{Obs}: observed values.

$$Z_{(1-\alpha)} = -\frac{\ln\left[COR \cdot \frac{1}{\sqrt{(CV_{Obs}^2+1)}}\right]}{\sqrt{\ln(CV_{Obs}^2 + 1)}} \quad (4)$$

Then, the compliance rate expected is compared to the actual compliance rate observed.

The study on reliability was developed based on the data distributed according to the lognormal model, and therefore, it was necessary to check the distribution frequency of the data related to the effluent turbidity before applying the model. The coefficients of asymmetry and kurtosis were used for preliminary verification of consistence of the data related to effluent plant as suggested by Helsel and Hirsch [10], and then the frequency of data distribution was verified by Pearson's chi-squared test and graphic test, namely *P*–*P* plot (probability–probability plot or percent–percent plot) carried out using Statistica 6.1.

The second stage of the reliability analysis consisted in calculating the expected compliance rate of the mentioned drinking water quality standards based on the values observed for effluent turbidity and the COR of the six plants by Eq. (4).

Based on such values of $(1 - \alpha)$, the values corresponding to the cumulative probability of the standardized normal distribution (*Z* distribution) were found using the NORM.DIST function of Microsoft Excel software. These values, which correspond to the area implied by the curve of standard normal deviate, are equivalent to the compliance rate attained. The stage of reliability model validation ended by comparing the expected compliance rate to the compliance rate effectively attained at the plants.

3. Results and discussion

3.1. Data collection

Monitoring period of each plant, within 2001 and 2011, and the number of data entries analyzed for the parameters of raw and treated water are shown in Table 2.

Besides the monitoring period, as shown in Table 2, the monitoring procedure frequency at the six plants also varied according to each parameter analyzed.

[1]Depending on the accumulated probability (reliability), this parameter takes the values 2.326 (99%), 1.645 (95%), 1.282 (90%), 0.842 (80%), 0.525 (70%), 0.253 (60%), and zero (50%).

There were parameters monitored daily, once, two times or three times a week, and finally, monthly.

3.2. Preliminary statistic analysis

At this stage, the verification of the presence of outliers showed that the vast majority of parameters presented values were perceived as extreme values. It is worth mentioning that the highest ratio of extreme values occurred at WTP III, and reached up to 16% of residual chlorine. This fact indicates a less uniform operation as concentration, theoretically, is not dependent on raw water quality and hydraulic parameters of the plant. On the other side, the WTP V and WTP VI had the lowest ratios and remained below 2% regard of the parameters being considered. Based on the ratio of the excluded data entries, and considering apparent color and turbidity parameters, it may be concluded that performance accomplishments have not been significantly affected. It is also worth pointing out that the removal of outliers can improve, in such way, the plant performance because the efficiency evaluation is done by means of the comparison between observed and set values established by mentioned Regulation 2914 [3].

After verifying the outliers, a seasonality analysis as described previously in Methods was performed following the descriptive statistics differentiation of data entries regarding wet and dry seasons. As an example, some descriptive statistics of WTP V are shown in Table 3.

Shapiro–Wilk normality tests applied to all water quality parameters in both periods at every plant, showed that none of such data entries presented adherence to normal distribution (p-value < 0.01) at (α) significance level of 5%. These results were determinant to the selection of the statistic tests applied to evaluate the performance of the plants.

3.3. Evaluation of the raw water quality

To evaluate the influence of the water source and the seasonality on the raw water quality, focus was directed to the parameters turbidity and apparent color.

To verify whether the raw water turbidity was influenced by the water source, nonparametric hypothesis tests were used according to the results of the normality tests that indicated an asymmetry of the data entries analyzed. Kruskal–Wallis tests were applied followed by multiple comparison tests at the significance level up to 5%. In case the difference between the turbidity values was significant for the same season, wet or dry, such difference could be attributed to the water source. It is worth pointing out that Box–Whisker charts were individually drawn for each plant regarding the raw water turbidity and apparent color over both periods, wet and dry.

In order to facilitate the interpretation of the results of Kruskal–Wallis nonparametric tests of independent samples, Fig. 1 was drawn to show significant differences between each plant (in bold letters) compared to the other ones (in italic letters) for raw water turbidity over the wet and dry periods.

The analysis represented in Fig. 1 shows that the raw water turbidity of WTP III was lower than the other ones in both seasons, which indicates a proper preservation of the watershed, as there are two intakes from impoundments (plans I and V). It is worth noticing that the higher raw water turbidity at WTP V may be due, besides the anthropic action, to the absence of a multilevel intake structure.

Table 2
Monitoring period and number of data entries of each parameter at the six plants for raw and treated water

Water treament plant	I	II	III	IV	V	VI	Total entries
Monitoring period	Jan/01 to Dec/11	Mar/01 to Dec/11	Jan/05 to Dec/11	Jan/01 to Sep/11	Jan/01 to Sep/11	Jan/01 to Jul/11	92,935
Inflow rate ($m^3 s^{-1}$)	0.132	2.091	0.144	0.127	0.127	0.127	2.748
Turbidity (NTU)	6,349	4,199	4,351	6,642	3,450	3,530	28,521
Apparent color (Hu)	6,367	4,188	4,327	6,564	3,450	3,527	28,423
Free chlorine (mg L^{-1})	3,215	2,100	2,177	3,325	1,751	1,765	14,333
Fluoride (mg L^{-1})	3,242	2,098	2,174	3,308	1,751	1,764	14,337
Total coliforms (MPN/100 mL)	3,013	–	1,162	398	–	–	4,573

Note: The records related to alkalinity and pH were excluded from data analyses.

Table 3
Descriptive statistics of WTP V over the dry season

Statistics	Inflow rate ($m^3 s^{-1}$)	pH RW[c]	pH TW[d]	Turb. RW (NTU)	Turb. TW (NTU)	Apparent color RW (Hu)	Apparent color TW (Hu)	Free chlorine TW ($mg L^{-1}$)	Fluor. TW ($mg L^{-1}$)
Number of entries	87	1,171	1,220	1,171	1,220	1,171	1,220	1,220	1,220
Medium	3.946	6.83	7.21	7.87	0.69	17.72	1.45	1.60	0.79
Median	3.859	6.86	7.21	5.82	0.46	15.08	1.00	1.60	0.79
Minimum	3.422	6.12	6.64	2.20	0.19	4.82	1.00	1.26	0.60
Maximum	4.571	7.46	7.80	32.80	5.85	50.67	14.33	2.34	0.99
Percentile 10%	3.487	6.52	7.01	3.56	0.33	9.58	1.00	1.42	0.71
Percentile 25%	3.617	6.68	7.10	4.41	0.38	10.58	1.00	1.50	0.75
Percentile 75%	4.302	6.99	7.32	9.84	0.62	22.92	1.00	1.69	0.83
Percentile 90%	4.387	7.11	7.41	14.48	1.18	30.33	1.33	1.76	0.87
SD[a]	0.358	0.23	0.16	5.08	0.71	8.47	1.86	0.14	0.06
CV[b]	0.09	0.03	0.02	0.65	1.03	0.48	1.29	0.09	0.08

[a]SD: standard deviation.
[b]CV: coefficient of variation.
[c]RW: raw water.
[d]TW: treated water.

Likewise, regarding the raw water apparent color, the results of Kruskal–Wallis nonparametric tests are shown in Fig. 2.

Also regarding to the apparent color, the WTP III influent showed lower values for this parameter compared to the other plants. Although not illustrated in Fig. 2, it was also noticed that the differences between the raw water quality become less evident during the wet season.

The combined analysis represented in Figs. 1 and 2 show the influence of the water source on the raw water quality was not so expressive as it was expected considering both parameters. It was found that the raw water turbidity was significantly higher in both types of water sources, lotic sources (WTP II and WTP VI) and lentic sources (WTP V), and a similar condition observed regarding apparent color. In this context, in terms of turbidity magnitude, the raw water quality is usually better in dry season than in wet season.

3.4. Evaluation of the effluent quality

As already mentioned, the effluent quality evaluation of each plant and somehow its performance was based on Kruskal–Wallis nonparametric tests and initially focused on four parameters, i.e. turbidity, apparent color, and residual chlorine and fluoride. Nevertheless, the apparent color magnitude of the influents of the sampled plants and the limit set by Brazilian and American drinking water standards (15 Hu) make the performance comparison useless regarding this parameter [3,9]. For example, from the total of 1,171 records of apparent color, only WTP I

(a) Dry Season

WTP I	WTP II	WTP III	WTP IV	WTP V	WTP VI	*WTP*
	↑	↓	↑	↑	↑	*I*
↓		↓	=	↑	↑	*II*
↑	↑		↑	↑	↑	*III*
↓	=	↓		↑	↑	*IV*
↓	↓	↓	↓		=	*V*
↓	↓	↓	↓	=		*VI*

(b) Wet Season

WTP I	WTP II	WTP III	WTP IV	WTP V	WTP VI	*WTP*
	↑	↓	↑	↑	↑	
↓		↓	↓	↓	↓	*I*
↑	↑		↑	↑	↑	*II*
↓	↑	↓		↑	↑	*III*
↓	↑	↓	↓		=	*IV*
↓	↑	↓	↓	=		*V*

Fig. 1. Significant differences ($\alpha = 5\%$) between each plant (in bold letters) compared to the other ones (in italic letters) regarding raw water turbidity.
Notes: ↑ in bold (above) statistically different/higher than the season in Italic letters (right column); ↓ in bold (above) statistically different/lower than the season in Italic letters (right column); = in bold (above) with no significant differences from the season represented in Italic letters (on the right).

was found to have an accomplishment level below the maximum, that is, 99.8% over the wet season and 99.9% over the dry season. Similar situation was noted with residual chlorine and fluoride.

Fig. 3 is based on effluent turbidity records, and is meant to identify statistically significant differences among the plants during dry and wet periods.

According to Fig. 3, it can be seen that there were differences among the four conventional plants (I, II, III, and IV), and that WTP III reached the highest performance. Considering all six plants, WTP VI showed highest performance in both seasons, and the opposite occurred with WTP I, except WTP IV in the wet season.

Such performance seems not to be related to the plant sizes. Despite the small number of the plants evaluated, it is possible to state that plant size has not entailed an indication of better performance as confirmed by the mentioned research carried out in the state of Pennsylvania [2]. The findings have not attested the superiority of two larger plants evaluated (WTP I and WTP V) but the high performance of the small to medium size plants (WTP III and WTP VI), respectively, in both seasons.

Regarding the compliance with the water quality target in terms of effluent turbidity, the comparison was focused on four limits: 1.0 and 0.5 NTU related to Brazilian drinking water quality standard and 0.3 and 0.1 NTU set by the American standard. A decision was made not to include the limit set by WHO [11] of 5.0 NTU, as less than 1.0% of the records related to effluent turbidity of plants IV and V were above such a limit. Table 4 shows the compliance rate regarding drinking water quality standards for both seasons.

Besides substantiating the performance superiority of the WTP III and WTP VI, the most outstanding finding that is brought forth by the analysis of the results shown in Table 4 indicates performance decrease of the plants over in the wet period compared to the dry season. Such percent compliance decrease is intensified as the limits become more restrictive. Such an event will take place at most plants in tropical countries. The exceptions were the plants of which influent reached high algae and cyanobacteria concentrations during the dry season.

The current Brazilian drinking water quality standard sets a maximum limit of 1.0 NTU for treated water turbidity, and progressive targets from 2013 and on. In such a context, in 2013 at least 25% of the effluent samples from the plants should have attained a turbidity lower than 0.5 NTU, percentage that must be raised to 50% in 2014, 75% in 2015, and 95% in 2016. In such situation, keeping the raw water quality unchanged, the hydraulic parameters inherent to the treatment steps and operating quality, only WTP VI is suited to reach such an objective.

As expected, the target set by USEPA, that is to say, 95% of the samples with turbidity lower than 0.3 NTU, has been met by WTP VI during the dry season. It is ultimately worth pointing out that the data entries refer to 2001–2011 period in which the drinking water standard in effect at the time had set a maximum effluent turbidity of 1.0 NTU.

3.5. Reliability analysis

The characterization of probability distribution of effluent turbidity records showed that the lognormal distribution could not be taken to describe the behavior of most of data entries. However, the data collected showed an asymmetric behavior towards the right, quite similar to the probability density function related to lognormal probability distribution. So, the reliability model developed and described by Niku et al. [5] was applied.

Fig. 4 shows the CV and the COR of the treated water turbidity of each plant. It may be seen in Fig. 4 the inverse behavior of the two coefficients, that is, the

(a) Dry Season

WTP						
I	**II**	**III**	**IV**	**V**	**VI**	*WTP*
	↑	↓	↑	↑	↑	*I*
↓		↓	↑	↑	↑	*II*
↑	↑		↑	↑	↑	*III*
↓	↓	↓		↓	↓	*IV*
↓	↓	↓	↑		=	*V*
↓	↓	↓	↑	=		*VI*

(b) Wet Season

WTP						
I	**II**	**III**	**IV**	**V**	**VI**	*WTP*
	↑	↓	↑	↑	↑	
↓		↓	=	↓	=	*I*
↑	↑		↑	↑	↑	*II*
↓	=	↓		↓	=	*III*
↓	↑	↓	↑		↑	*IV*
↓	=	↓	=	↓		*V*

Fig. 2. Significant differences ($\alpha = 5\%$) between each plant (in bold letters) compared to the other ones (in italic letters) regarding raw water apparent color.

Notes: ↑ in bold (above) statistically different/higher than the season in italic letters (right column);↓ in bold (above) statistically different/lower than the season in italic letters (right column); = in bold (above) with no significant differences from the season represented in Italic letters (on the right).

(a) Dry Season

WTP						
I	**II**	**III**	**IV**	**V**	**VI**	*WTP*
	↓	↓	↓	↓	↓	*I*
↑		↓	↑	=	↓	*II*
↑	↑		↑	↑	↓	*III*
↑	↓	↓		↓	↓	*IV*
↑	=	↓	↑		↓	*V*
↑	↑	↑	↑	↑		*VI*

(b) Wet Season

WTP						
I	**II**	**III**	**IV**	**V**	**VI**	*WTP*
	↓	↓	=	↓	↓	
↑		↓	↑	=	↓	*I*
↑	↑		↑	↑	↓	*II*
=	↓	↓		↓	↓	*III*
↑	=	↓	↑		↓	*IV*
↑	↑	↑	↑	↑		*V*

Fig. 3. Significant differences ($\alpha = 5\%$) between each plant (in bold letters) compared to the other ones (in italic letters) regarding treated water turbidity during dry and wet seasons.
Notes: ↑ in bold (above) statistically different/higher than the season in italic letters (right column) ↓ in bold (above) statistically different/lower than the season in italic letters (right column) = in bold (above) with no significant differences from the season represented in italic letters (on the right).

Table 4
Compliance rates (%) regarding quality target of the six plants evaluated in dry and wet seasons

WTP	1.0 NTU	0.5 NTU	0.3 NTU	0.1 NTU
	Dry season			
I	69.4	11.5	3.9	3.7
II	98.5	60.8	5.7	0.0
III	99.6	74.5	17.3	0.0
IV	90.9	28.3	0.6	0.0
V	89.7	66.7	5.2	0.0
VI	99.9	99.4	97.8	17.9
	Wet season			
I	58.1	9.4	5.9	5.7
II	90.9	38.8	2.7	0.0
III	99.9	72.7	11.9	0.0
IV	74.0	13.5	0.5	0.0
V	84.2	41.3	2.2	0.0
VI	99.5	96.9	84.5	2.0

higher is the CV, the lower is the COR as the plant shows a more instable performance.

It is once more underlined that raw water quality and the plant size had no significant influence on the performance reliability of the sampled plants as the units of different sizes showed lower COR. Similarly, the highest COR was reached by a small size plant.

In order to estimate the performance level required to reach the effluent quality targets, using Eq. (1), Fig. 5 was drawn to exemplify a performance comparison of all plants. Fig. 5 shows the mean values found for effluent turbidity of each plant compared against the mean target values for reliability (α) of 95% in order to reach the limits set by the Regulation 2914 that will be in effect in 2015.

The effluent turbidity values required to conform to the Regulation 2014 [3] take into account the performance variability of each plant and again shows the superiority of WTP VI compared to the other ones, as the target required value showed to be lower than the one actually recorded.

Finally, as described previously under Methods and in prospective analysis, Eq. (4) was used to estimate the rates of compliance that each plant would reach, while keeping the same plant operating parameters. By considering the limits set by Brazilian drinking water standard of 1.0 NTU and 0.5 NTU, and the American standard or 0.3 NTU, respectively,

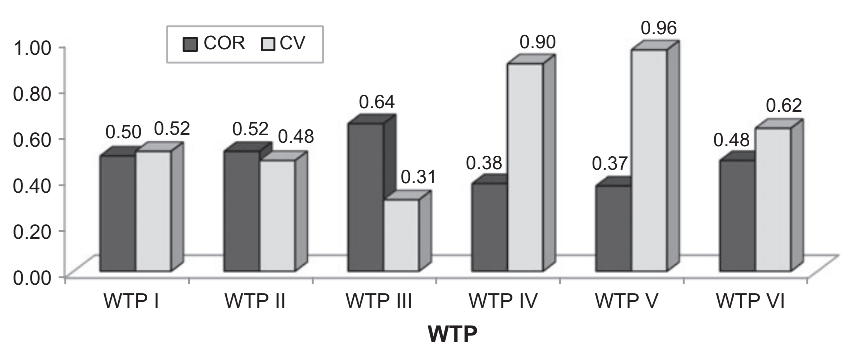

Fig. 4. Coefficients of reliability (COR) and variation (CV) of treated water turbidity ($\alpha = 5\%$).

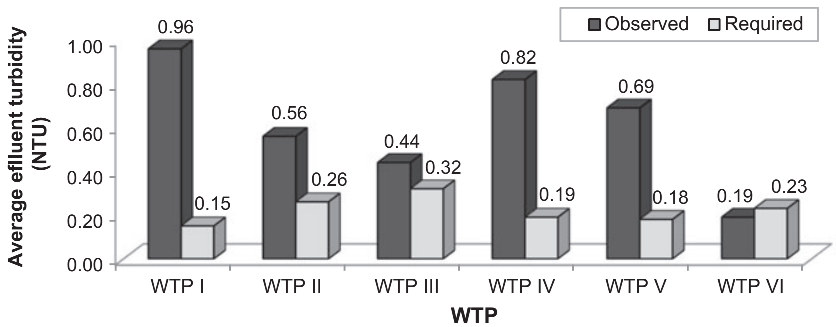

Fig. 5. Mean values of effluent turbidity recorded and required to comply with the Regulation 2914 [3] in 2015.

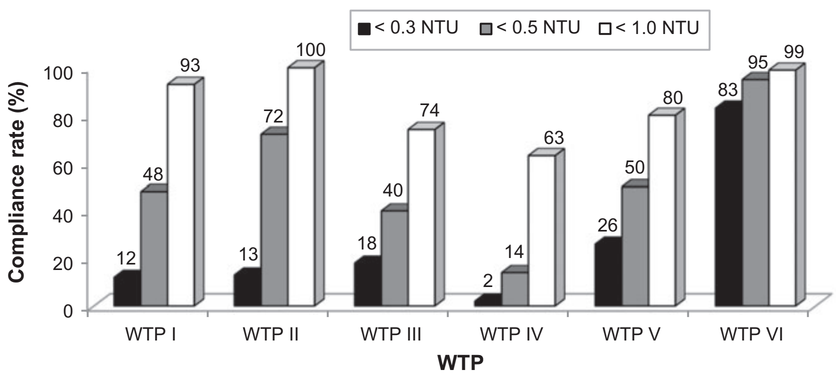

Fig. 6. Expected compliance rate for the three effluent turbidity limits (α = 95%).

the compliance rates were projected based on the COR as shown in Fig. 6.

As presumed, the expected compliance rate is higher when the turbidity standards are less restrictive as it is the case of standard set up to 1.0 NTU. On the other hand, for the standard set up to 0.3 NTU, for example, the minimum compliance rate is reached in very low percentages at WTP IV. So, it is once more confirmed what has already been found in previous analyses, i.e. the optimal performance of WTP VI compared to the other plants.

4. Conclusions

The main conclusion of this study was the confirmation of the feasibility of the application of the stated statistical tools to evaluate the WTP performance focused on average daily records of water quality parameters. This methodology could be replicated to other WTP since the operational data-set was suitable. Based on the results found using statistical tools, it's possible to conclude that:

(1) As the raw water quality deteriorates in terms of increase in turbidity, the hydraulic and operational limitations of water treatment plant becomes more evident. In this study, no performance improvement has been observed when comparing wet season and dry season at none of plants evaluated. Therefore, except the plants for which influent come from water sources that may have undergone severe eutrophication events, the performance evaluation may only be based on operating data recorded over the wet season, i.e. when worse conditions comes out;

(2) The plant performance does not seem to relate to raw water quality, and neither to water treatment plant size. Such assertion is substantiated by the lower performance of the larger size plants such as WTP I and WTP V compared to the performance of WTP III. However, it is not possible to conclude definitely about the supremacy of small size plants in comparison with the large size ones due low number of plants evaluated.

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