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PROPOSITION OF A NEW APPROACH FOR ESTIMATING DRY MASS GENERATED IN WATER TREATMENT PLANTS IN PARANÁ/BR

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Abstract: Water treatment plants (WTPs) that operate through conventional treatment processes produce large quantities of sludge, called WTP sludge, which are classified as solid waste in countries in Latin America, the European Union and the United States. An important step in sludge management consists of reducing the volume to be disposed of, requiring the correct quantification of sludge produced at the stations, very often carried out using empirical equations from the literature, which consider the characteristics of raw water, such as total suspended solids. (SST) or Turbidity (T) together with a multiplication coefficient to obtain SST, and reagents added in water treatment. Due to the qualitative differences in the water used for supply and the different characteristics of the reagents, the objective of the present work was to evaluate the applicability of these equations and propose a new approach for estimating the dry mass generated in ETAs located in the Pirapó Hydrographic Unit (UH), Paranapanema 3 and 4 in the state of Paraná, based on real correlations between T and SST. For this, a history of data on these parameters in raw water from the mentioned UH was used and, with the application of statistical methods, a new equation was obtained for determining TSS from T. The precipitates of the chemical products were also verified used in the treatment, based on stoichiometric relationships with water, to compose the portion of sludge generated from the products, which, added to the portion resulting from the quality of raw water, gave rise to the new equation for estimating the dry mass generated in ETAs in this region. To compare the results obtained with the new equation with those from the literature equations, an ETA was selected in this region and real measurements of the dry mass generated were made from the dewatered sludge destined. The results obtained with the measurements and the application of literature equations had differences of 28 to 65%, depending on the equation, significantly greater than the difference obtained when comparing the real values with the new proposed equation, of -0, 64%. Considering the local characteristics of the water and the chemical reagents used in the treatment is, therefore, essential for a more accurate calculation of sludge production in ETAs. It is believed that the new approach proposed in this work can improve the design of sludge treatment plants, especially in new ETAs, where real measurements are not possible to determine the dry mass generated, a very common situation in Brazil.

Keywords: ETA sludge; Quantity of Sludge; Sludge Management.

INTRODUCTION

The different sources of raw water used for public supply require the application of different treatment processes, depending on the quality of the water collected, with conventional full-cycle treatment being the most used in several countries, including Brazil. In the solid-liquid separation stage, the waste generated is commonly called ETA sludge (LETAs), and can be classified as solid, hazardous or organic waste, according to the regulations in force in the country (ABNT, 2004). Water concessionaires and operators must, therefore, follow the guidelines of the National Solid Waste Policy, Federal Law No. 12,305/2010 (BRASIL, 2010) for the management of LETAs, with their environmentally appropriate disposal being mandatory. To reduce the costs of the various activities and operations of LETA management, processes are used to remove the water present in LETAs, and their sizing is highly dependent on their qualitative and quantitative characteristics, which vary with the quality of the raw water captured, the chemical reagents used in the treatment, among other factors.

For quantitative characterization, the estimation method is commonly used based on empirical equations from the literature (AWWA, 1978; AWWA, 1999; REALI, 1999, RICHTER, 2009), which mostly use as variables the concentration of total suspended solids. (SST) of raw water and precipitates from chemicals used in the water treatment plant (ETA). In the absence of SST data, it is common to use turbidity (T) and multiply it by a coefficient, suggesting a linear relationship between the parameters. In some research, the correlation between SST and T was evaluated and it was concluded that it is highly local, and must be analyzed in each case to avoid undersizing in units designed to drain the sludge and sending surplus to the water body, or oversizing and investments overpriced (KATAYAMA et al., 2015; THACKSTON and PALERMO, 2000; AHMAD et al., 2017).

In the state of Paraná, which has 168 conventional water treatment plants operated by a single concessionaire throughout the state and providing around 100 thousand m^3.h-1 of drinking water, it is estimated that hundreds of thousands of tons of sludge, and its precise characterization is essential for adequate management of this waste.

Due to the fact that there are different Basins or Hydrographic Units (HUs) in Paraná, which regionalize the characteristics of the spring waters, and due to the fact that the amount of sludge generated in a ETA depends on these characteristics, an alternative for quantitative characterization is the proposition of a new regionalized model for estimating dry mass production in ETAs, based on verifying the correlation between SST and T of each HU. Thus, the general objective of this work is to propose a new dry mass production equation (DMP) in ETAs located at UH Pirapó, Paranapanema 3 and Paranapanema 4 and compare the results with the quantities of dewatered sludge destined.

The specific objectives are as follows:

- Verify the real correlation between T and SST of raw water from the sources of the aforementioned UH;
- Compare the results obtained for PMS with new correlation between parameters with those from literature equations;
- Check the error obtained when comparing the literature equations with the amount of dewatered sludge destined for the UH ETA.

MATERIALS AND METHODS

To fulfill the objectives of the work, the methodological steps described below were followed.

DATA HISTORY – SST AND T ANALYSIS

Results of SST and T analyzes were used in the raw water influent to the ETAs represented in Figure 1, belonging to UH Pirapó/ Paranapanema 3 and 4, with the sample size (n) equal to 43 data points.

DATA ANALYSIS – CORRELATION BETWEEN SST AND T

For the portion of sludge produced based on the characteristics of raw water, that is, based on the concentration of total suspended solids, the correlation between SST and UH T was verified using scatter plots and the Pearson Coefficient. If this coefficient was equal to 1.0, it was possible to verify the linear relationship between the parameters, simply by evaluating K1 for each SST.

If not, the trend lines were plotted and the coefficients of determination (r^2) were checked, determined by Equation 1:

$$\mathbf{r}^2 = \frac{\sum_{i=1}^{n}(\hat{y}i-\bar{y})^2}{\sum_{i=1}^{n}(yi-\bar{y})^2} \qquad \text{Equation 1}$$

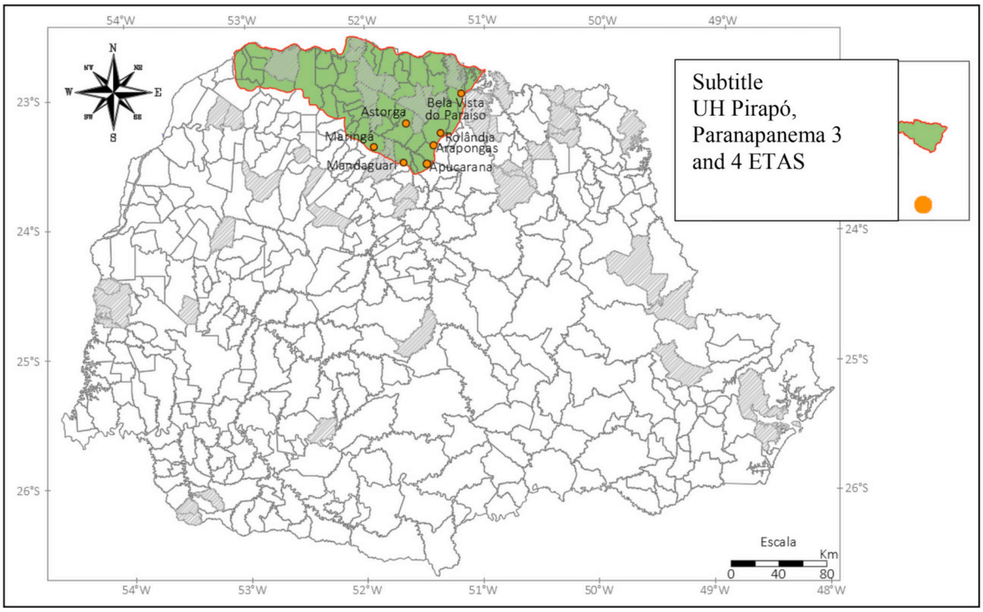

Figure 1: State of Paraná with ETAs of UH Pirapó, Paranapanema 3 and 4.

In which the numerator is equal to the sum of squares due to the regression, which represents the difference between its mean and the value of y that would be predicted from the regression relationship, and the denominator, the total sum of squares, or the variation in y values around their arithmetic mean plus unexplained variations - y values that are not explained by the regression. The closer to 1.00, the better the correlation.

For the best r^2 obtained, regression analysis was performed using the Least Squares Method (MMQ) after linearization, solving the system:

$$\begin{cases} \mathbf{na} + \left(\sum_{i=1}^{n} \mathbf{x_i}\right)\mathbf{b} = \sum_{i=1}^{n} \mathbf{y_i} \\ \left(\sum_{i=1}^{n} \mathbf{x_i}\right)\mathbf{a} + \left(\sum_{i=1}^{n} \mathbf{x_i^2}\right)\mathbf{b} = \sum_{i=1}^{n} \mathbf{x_i y_i} \end{cases}$$

For the new model generated, the suitability assumptions are verified: normality, homoscedasticity, independence and linearity (LEVINE et al., 1998).

MULTIPLICATION COEFFICIENT – CHEMICAL PRODUCTS

For the portion of sludge originating from the precipitates of chemical products added in the ETAs, especially the coagulant, and considering that the one used in the ETAs in the study area is polyaluminum chloride (PAC), and that its K coefficient is not available in the majority From the equations in the literature, this coefficient was calculated according to the relationship between the molar masses of the chemical product and its precipitate, and the concentration of the product as a function of the added aluminum.

The precipitation of aluminum salts in an aqueous medium occurs according to Equation 2:

$$Al^{+3} + 3OH^{-} + nH_2O \rightarrow Al(OH)_3 \cdot nH_2O \qquad \text{Equation 2}$$

being the number of waters of hydration (ranging from 1 to 3), for the maximum value of n, the molar mass of the precipitate will be 132 g. Since the molar mass of aluminum is 27 g, for every 1 mg. L-1 of Al added in the treatment, 4.89 mg. L-1 of solids will be generated (132 g / 27 g).

To obtain the relationship of solids generated from the addition of 1 mg. L-1 of PAC, the percentage of Al present was identified based on the alumina concentration (Al2O3) and the mass/mass concentration (information provided by the manufacturer).

NEW EQUATION FOR PMS AT UH

The new PMS estimation equation at UH was formulated based on the sum of the portion of sludge generated from: a) characteristics of the raw water, that is, the TSS concentration, which in turn is determined from T (correlation obtained in the previous steps); and b) coagulant precipitates, using K obtained in the previous steps.

APPLICATION OF THE NEW EQUATION AND COMPARISON OF RESULTS

Based on operational data from a given ETA in 2021, the dry mass production obtained from the new proposed equation (PMSe) and the real one from the station (PMSd) was calculated, calculated from the amount of dewatered sludge destined (LDD).

Furthermore, a comparison was also made with the results obtained from the PMS equations in the literature.

RESULTS

DATA ANALYSIS – CORRELATION BETWEEN SST ET

From the history of SST and T analyzes in the water supply of the study HPP, it was found that the Pearson coefficient obtained between the parameters was 0.86, that is, the relationship between them is not completely linear.

By plotting several trend curves, as shown in Figure 2, it was observed that the one with the best R^2 was the degree 2 polynomial.

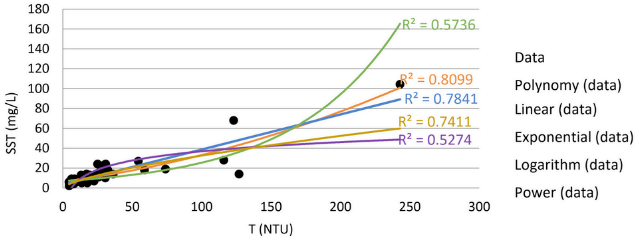

Figure 2: Trend curves for historical data.

With the application of polynomial regression analysis, using the least squares method, the coefficients a, b and c, of the polynomials $y = ax^2 + bx + c$ for the UH were obtained, in which y = SST and x = T, being: $a = 0.0009$; $b = 0.182$; $c = 6.4182$, with determination of SST from T according to Equation 3.

$$SST = 0{,}0009 \cdot T^2 + 0{,}182 \cdot T + 6{,}4182 \quad \text{Equation 3}$$

Compliance with the model's suitability assumptions was verified using the graphs in Figures 3 and 4.

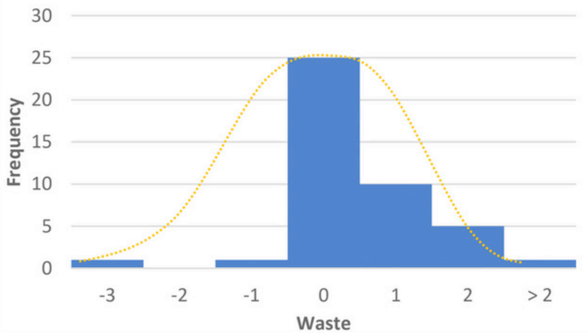

Figure 3: Regression residual frequency graph. UH Pirapó, Paranapanema 3 and Paranapanema 4.

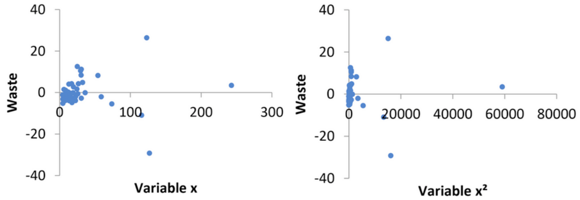

Figure 4: Residue graphs for each variable. Left: Variable x - UH PP3e4. Right: Variable x^2 - UH PP3e4

MULTIPLICATION COEFFICIENT – CHEMICAL PRODUCTS

For the value of K, when using PAC, the product concentration is equal to 37% mass/mass and has 10.7% Al2O3 (102 g.mol-1), resulting in 29% Al2O3 (1/37% x 10.73% = 29%) and 15.3% Al (54/102 x 29%) in the product. Thus, for every 1 mg. L-1 of PAC added, 0.751 mg. L-1 of solids are generated (15.35% x 4.89 mg. L-1), this being the value of the multiplication coefficient for the dosage of the reagent.

NEW EQUATION FOR PMS AT UH

The new PMS equation at the study HU resulting from the previous calculations is given in Equation 3:

$$PMS = 0{,}0009 \cdot T^2 + 0{,}182 \cdot T + 6{,}4182 + 0{,}751 \cdot D_{PAC} \quad \text{Equation 3}$$

being:

- PMS = dry mass production, in kg.m-3;
- T= Raw water turbidity, in NTU;
- DPAC = dosage of polyaluminum chloride, in mg. L-1.

APPLICATION OF THE NEW EQUATION AND COMPARISON OF RESULTS

Applying the new equation at ETA located at UH, the monthly PMSe dry mass production was obtained from January to October 2021. The values were compared to the dry mass production obtained from the quantities of dewatered sludge destined (LDD), called PMSd. The results and comparison between each PMS are found in Table 1.

Both previous dry mass production results (PMSe and PMSd) were compared with those resulting from some literature equations (shown in Table 2). The values obtained and the differences between results are presented in Table 3.

Reference	Equations
WWWA (1978)	$PMS = 3{,}5 \times 10^{-3} \cdot T^{0{,}66}$ Equation 4
RICHTER (2009)	$PMS = \frac{0{,}2 \cdot C + K_1 \cdot T + K_2 \cdot D}{1000}$ Equation 5
AWWA (2010)	$PMS = \frac{(0{,}44 \cdot D_{SA} + 2{,}9 \cdot D_{FE} + 0{,}8 \cdot D_{PAC}) + SST + OA}{1000}$ Equation 6

Table 2 – Estimation equations for dry mass generated in ETAs.

PMS = mass of dry solids produced in kg.m-3 of treated water; C = color of raw water, in °H; T = raw water turbidity, in NTU; D = coagulant dosage, in mg.L-1; DSA = aluminum sulfate, DFE = for dosage in mgFe.L-1, DPAC = polyaluminum chloride; SST = solids suspended in raw water, in mgSST.L-1 (expressed as, with b between 0.7 and 2.2); OA = other additives, in mg.L-1; K1 = between 0.5 and 2.0; K2 = 0.26, 0.40 and 0.54, for aluminum sulfate, ferric chloride and ferric sulfate, respectively.

RESULTS ANALYSIS

From the trend curves plotted for the SST and T parameters of raw water from the UH Pirapó, Paranapanema 3 and 4 ETAs, it was verified that the linear relationship suggested in the literature for the parameters is not applicable in this region, since the one that presented the best coefficient of determination R^2 was the polynomial of degree 2, compatible with some research that suggested this correlation (CHAGAS, 2015; NAVRATIL et al., 2011).

The coefficient calculated for multiplication by the PAC dosage also differs from those given for aluminum salts in literature equations, and it is therefore recommended to evaluate the relationship between the molar masses of reactants and their precipitates whenever possible, to confirm K.

From the comparison between the dry mass results obtained with the new equation (PMSe) and those obtained from the quantities

Month	T raw water (NTU)	DPAC (mg. L-1)	LDD (kg. month-1)	PMSd1 (kg. month-1)	PMSe2 (kg. month-1)	PMS difference (%)
Jan/21	46.4	7.6	62,170	20,516	15,529	-37.46%
Feb/21	62.2	69.9	73,800	24,354	52,012	62.02%
Mar/21	93.4	8.4	83,060	27,410	25,651	-7.99%
Apr/21	21.0	4.8	55,870	18,437	9,857	-101.53%
May/21	23.9	5.3	50,400	16,632	10,513	-67.89%
Jun/21	15.2	4.8	33,350	11,006	8,602	-32.59%
Jul/21	11.0	4.6	36,870	12,167	7,893	-63.16%
Aug/21	7.7	6.3	18,400	6,072	8,476	33.08%
Sep/21	11.9	8.7	68,790	22,701	10,442	-136.93%
Oct/21	115.6	11.0	69,930	23,077	32,232	33.13%
			Sum period	**182,371**	**181,206**	**-0.64%**

Table1– PMS results and comparison between results

1 average solids content in the dewatered sludge = 33%; 2 applied three times the efficiency of 95%.

Operational data				Dry mass production (kg. month-1)				
Month	T raw water (NTU)	DPAC (mg. L-1)	Color (uH)	As dewatered sludge intended	New proposed equation	WWWA (1978)	RICHTER1 (2009)	AWWA2 (2010)
Jan/21	46.4	7.6	105	20,516	15,529	30,377	57,491	50,579
Feb/21	62.2	69.9	171	24,354	52,012	37,693	93,973	103,050
Mar/21	93.4	8.4	223	27,410	25,651	47,712	114,850	97,025
Apr/21	21.0	4.8	46	18,437	9,857	18,053	26,060	23,700
May/21	23.9	5.3	55	16,632	10,513	19,575	29,858	26,759
Jun/21	15.2	4.8	40	11,006	8,602	13,944	19,156	17,097
Jul/21	11.0	4.6	30	12,167	7,893	11,256	14,133	12,959
Aug/21	7.7	6.3	20	6,072	8,476	9,014	10,469	10,842
Sep/21	11.9	8.7	29	22,701	10,442	12,267	16,155	16,570
Oct/21	115.6	11.0	274	23,077	32,232	54,337	140,455	119,119
			Sum	182,371	181,206	254,228	522,600	477,699
			Diff. (%)	-	-0.64%	28%	65%	62%

Table 3 – PMS results according to equations

1 Used K1 = 1.3, cited by the author as more common, and K2 = 0.26, given for another coagulant based on aluminum salt; 2 used K1 = 1.45, being the average value between the range given by the author.

of dewatered sludge intended (PMSd), and considering the sums of the periods, a difference of -0.64 was obtained %, validating the proposed equation for estimating the sludge generated at this ETA.

Furthermore, with the application of equations from the literature to calculate the dry mass generated at the station in the same period, and the comparison of the results with those resulting from the amount of dewatered sludge destined, differences of 28 to 65% were verified, depending on the equation.

CONCLUSIONS

At UH Pirapó, Paranapanema 3 and Paranapanema 4, in the state of Paraná, it was found that the correlation between SST and raw water turbidity is not linear as suggested in the literature, but is given by a polynomial of degree 2. Using the appropriate correlation for the parameters, we have an estimate of dry mass generated in ETAs closer to the real quantity, which cannot be observed when using literature equations, without considering these differences in raw water.

For the ETA of the study, in all cases, the dry mass values obtained from the literature equations were greater than those measured (full scale) at the ETA, which probably results in over dimensioning and higher investment costs in drainage structures of sludge, if such a conventional approach is adopted in projects. The present work proves the need to verify the correlation between SST and T in raw water used for supply and the potential of the new regionalized model for estimating dry mass generated in ETAs for better management of this waste and sizing of drainage equipment.

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