



THE ALUMINUM SPECIE ASSESSMENT BY DECISION MAKING TOOL: CHEMICAL METROLOGY AND QUALITY ASSURANCE RESULTS

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Abstract: Aluminum is very abundant and can be found dissolved in water. Local environmental agencies have monitored water quality of public dams over the last 10 years however the test results showed fluctuations causing difficulties with assessing water quality level and the possible risks to human health. This paper aims to propose a newer decision making tool to support risk assessment based on public data reports from CETESB. Doing simulations with data from Billings' dam, for aluminum specie, the author has demonstrated this to be a powerful tool to support environmental efforts.

Key words: aluminum, quality water, decision making tool, Alto Tietê Basin

1. INTRODUCTION

The quality management of water resources in Brazil was later developed, compared to the accelerated population growth. It has caused over the years the contamination of waters by domestic and industrial effluents without proper treatment. Despite being a well known problem, much of the population has little or no access to information updated about water quality. Reservoirs that were not originally designed for public supply, but are utilized for this purpose, needs special attention because many of them are polluted and need constant monitoring by regulatory agencies and society to ensure their potability.

Quality testing reports from public bodies such as CETESB (Environmental Agency) are important, especially when the historical evolution is considered. They also enable the actual trend of rise or fall of water quality to be followed. Nevertheless, sometimes it is still difficult to conclude what is the real status of water quality and possible risk to human health and to environmental when the results fluctuate over time. [1].

This paper aims to present a tool to support risk management of water quality, based on data available from CETESB's published database. The spreadsheet tool results in five levels of alarm that can support a

decision on the mitigation actions either communication of community impacted. As an example, we used data of aluminum specie from public water dam.

1.1. The Case Studied - Billings Reservoir (Alto Tietê Basin)

The Billings reservoir is located in highly populated and industrialized regions. It receives discharges of organic compounds, heavy metals and nutrients which greatly impair water and sediment quality. It is extremely important due to the fact that it is the largest water reservoirs for South America's largest city, São Paulo, Brazil. It is located within the Metropolitan Region of São Paulo – RMSP, and occupies an area of approximately 582.8 km². The reservoir produces 12 m³/s of the water that supplies the Great ABC, part of São Paulo and Santista lowland. Also is characterized by environmental impacts form urban invasion, industrial and sewage wastes, all of which seriously affect its ecosystems and quality life of population of the region.

Many studies were published of distribution of heavy metals and intense pollution loads in water samples from the Billings. In 2005, the Fishing Institute (SP, Brazil) initiated a monitoring program of the fishing production proceeding from fishing artisan professional, studied as base the fished number nucleon fishing, fishes species, water and sediment quality's of reservoir Billings. This tool will help, for example, in assessment the quality assurance these results and any studied region.

1.2 Aluminum

Aluminum is the most abundant metal in the earth's crust. It is always found combined with other elements such as oxygen, silicon, and fluorine. The metallic form of aluminum is obtained from aluminum-containing minerals. Small amounts of aluminum can be found dissolved in water. [2].

It connects to fluorides, sulfates and especially with humic substances (HS), as humic acid (HA), for

example. The toxicity is related to its chemical form. The most dangerous is the free cation (Al^{3+}). Aluminum sulphate is widely used in water treatment as flocculant, it binds and forms complexes with organic matter.

Resolution 357/2005 from CONAMA states dissolved aluminum levels of surface waters (Class II), must be below 0.1 mg/L. This resolution establishes classes of freshwater, brackish and saline according to their predominant uses and defines their quality standards.

However, this resolution, recently complemented by 397/08, ordered the parameter aluminum dissolved out instead of total aluminum. The detection of dissolved aluminum, the methodology requires water filtration membrane of cellulose or nylon with porosity of 0.45 microns, for example, and precision equipment. The change in the diagnosis of the metal in dissolved form was relevant, since the metal is in suspension and in the most toxic and free for complexation with other substances, and in many cases, water treatment satisfaction dissolved aluminum is inefficient, because aluminum is not removed.

Water indicators of São Paulo metropolitan region show high dissolved aluminum concentration in public dam water, like Billings dam [3]. Aluminum was selected for this study, although any other elements could also have been used, due to the following aspects:

1. Toxicity to humans: oral, through of drinking water, residues in food, housewares, packaging, antacids and antiperspirants formulas [4].
2. Related diseases: seborrhea, cerebral sclerosis (Alzheimer's), irritability, movement of calcium and magnesium from bones and osteoporosis [5, 6].

2. METHODS

Based on historical data from CETESB, a spreadsheet tool was developed to support environmental efforts to manage water quality. The decision making tool uses the similar concept of a FMEA (failure mode and effect analysis) tool in which the final product is the "alarm" level [7]. The main objective of this tool is to provide greater objectivity when interpreting analytical results.

As well as FMEA tool, three main factors (A, B and C) give the final product.

- A. History of non-compliance
Indicates what percentage of the analysis results were above the limit allowed by public resolution. Function has to give weight to the history.

- B. Latest result
Indicates the trend on the rise or fall of water quality monitored. It also has the function of giving weight to the momentary result.
- C. Frequency of testing
The higher the frequency, the greater the degree of monitoring and therefore a higher the level of information available for decision making. Function has to give weight to the level of certainty.

Table 1 shows the ten levels of classification based on the three factors (A, B and C) and give the respect range of values.

Table 1. Levels for Three Decision Factors

Level (n)	History of Non-compliance (%)	Latest Result (mg/L)	Frequency of testing
1	0-10.0	$\leq 0,002$	Not regular
2	10.1-20.0	0.003-0.005	Biennial
3	20.1-30.0	0.006-0,014	Annual
4	30.1-40.0	0.015-0.037	Semiannual
5	40.1-50.0	0.038-0.100	Quarterly
6	50.1-60.0	0.101-0.272	Bimonthly
7	60.1-70.0	0.273-0.740	Monthly
8	70.1-80.0	0.741-2.012	Weekly
9	80.1-90.0	2.013-5.740	Diary
10	90.1-100.0	5.741-14.87	Hourly
Factor	[A]	[B]	[C]

The range of Latest Result column was defined used the equation 1. The main reason to use it was: a. exponential function gives a large range that could cover true situation. It is possible to cover up to 14.87 mg/L, which is 150 times greater than the limit; b. the adjustment constant (0.000675), which was defined empirically, gives more accuracy for the limit level that is being used from CETESB for aluminum (0.1 mg/L) at level 5. Conceptually any result above level 5 is out of limit permitted.

The reference value for total aluminum, according to the Ordinance 518/04 of the Ministry of Health for drinking water is 0.2 mg/L and the reference value for aluminum dissolved to water class 2, according to Resolution 357/05 CONAMA is 0.1 mg/L.

$$B = 0.000675 \cdot e^n \quad (1)$$

Final score is calculated using the factors A, B and C, showed in equation 2.

$$Score = A^2 \cdot B^2 \cdot C \quad (2)$$

Factors A and B, history of non-compliance and latest results, respectively, were weighted twice because both of them are quantitative and give us more data about the true impact on the level of water quality

level in despite to factor C (frequency of testing) that is a more qualitative factor.

The final score ranges from 1 to 100,000. Therefore the Alarm score has 5 levels as showed in Table 2:

Table 2. Range and Alarm Level

n	Alarm Level	Score Range
1	Minimum	1 – 366
2	Limitary	367 – 1,991
3	Warning	1,992 – 8,120
4	Danger	8,121 – 29,430
5	Maximum	29,431- 100,000

The alarm level range was defined using the following equation 3. The main reason is to have for n = 0, Score Range = 0 and for n = 5, Score Range = 100,000, using exponential basis. The adjustment constant 134.75894 was also defined empirically to meet these assumptions.

$$ScoreRange = 134.75894 \cdot n \cdot e^n \quad (3)$$

The alarm level could be translated accordingly to following explanation as follow:

1. Minimum
Any risk to human health. Any recommendation must be implemented
2. Limitary
Low risk to human health. Additional monitoring is required to confirm results
3. Warning
Potential risk to human health. Requires attention and minor efforts to remediate contamination
4. Danger
Imminent risk to human health. Requires major efforts to remediate contamination
5. Maximum
Out of control. High risk to human health. Requires immediate intervention and an emergency plan is highly recommended

2.1 Example

To show how the decision making tool work, an example is shown as follow.

Data:

- Non-compliance Historically: 70% (A = 7)
- Latest Result: < 0.25 mg/L (B = 6)
- Frequency of testing: bimonthly (C = 6)

Calculation:

$$Score = A^2 * B^2 * C$$

$$Score = 7^2 * 6^2 * 6 = 10,584$$

Alarm Level 4 – Danger

This result means there is an imminent risk to human health since the contamination doesn't show any evidence of reducing. It also shows that the contamination is cumulative and will be hardly dissipated if a complex plan to remediate is not properly implemented.

3. RESULTS AND DISCUSSION

Three specific sample points were used to support this study in Billings' dam. Their names and specific location is listed in Table 3.

Table 3. List of Samples Points, Billings dam (adapted by CETESB)

Location name	Place
BILL 02100	The central body toward the Bororé region
BILL 02900	Summit control
BILL 02500	The central body under the highway bridge of Imigrantes

Aluminum species was selected as the element under evaluation. Maximum values for each year were summarized from CETESB reports available in their website published during period from 2000 to 2009 and compared to CONAMA's limit level (Table 4).

It is quite difficult to make any conclusions on how the actual states of the quality issue from analysis test. There was fluctuation however considering the percentage of non-compliance (Figure 1), it is possible to verify a decreasing trend.

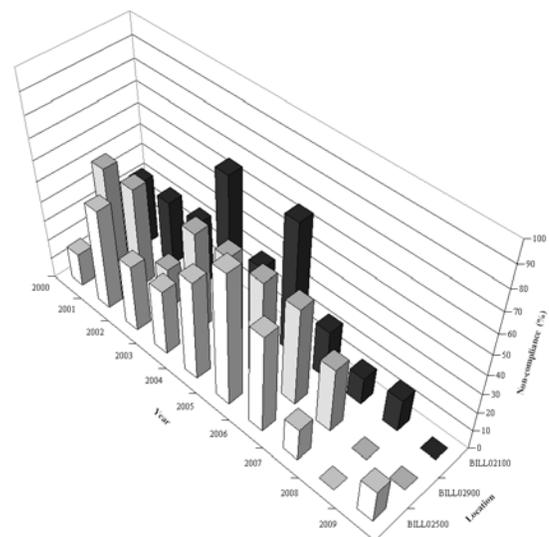


Fig. 1. Percentage of Non-compliance Results

There are two periods to be reported, which concentrate on the worst historical percentage of non-compliance - equal or greater than 50%, in 2000 and 2001, and 2003 and 2006, which is clearly viewed in the graph. These percentages are cumulative since the first data available from CETESB and give the historical information about each point studied (from 2000 to 2009).

Calculating the score for each year and sample point, we could understand historical progression of the contamination. It's also possible to understand their dynamic comparing each other. Results of risk scores year by year are graphically demonstrated in Figure 2.

More than 93% of the risk scores were positioned in "Attention" alarm level, with results from 2400 and 7776 in all samples points. About 3% were positioned in "Limitary" alarm level. It represents only one sample point (BILL02500) in 2000 with risk score of 864.

It was found one "Danger" alarm level in BILL 02900, with risk score of 9600, year 2007, contributing to 3% of the results.

Analyzing the whole picture, we could say there is a potential risk to human health, especially to people who use water regularly Billings' dam in their alimentation (e.g. fishery or agricultural).

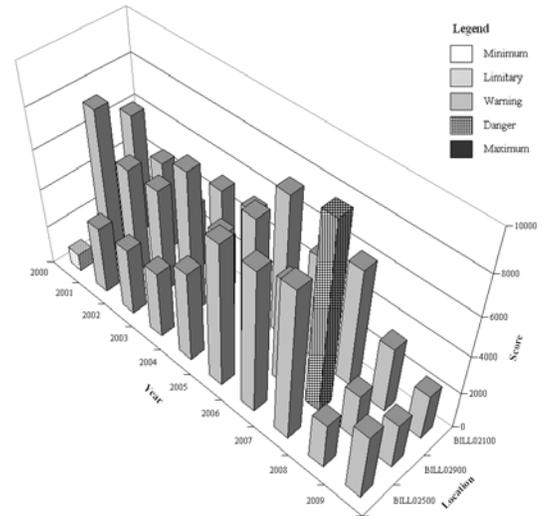


Fig. 2. Risk Scores

Metrological bases show that to obtain reliable information, there should be made of many paths, repetition and control, implying a higher frequency of monitoring and hence a greater safety margin in the results [8, 9].

Table 4. Aluminum Results at Billings dam, adapted by CETESB

Location	Parameters	Total Aluminum (mg/L) according to CONAMA 20/86						Dissolved Aluminum (mg/L) according to CONAMA 357/05			
		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
BILL02500	Latest result (Max. Annual Value)	0.19	0.15	0.19	0.19	0.38	0.46	0.49	3.01	<0.1	0.11
	# Results above limit	1	3	2	2	3	4	2	1	0	1
	# Tests Performed	6	6	6	6	6	6	4	6	6	6
	Non-compliance cumulative (%)	17	33	33	33	37	42	43	39	35	33
BILL02900	Latest result (Max. Annual Value)	0.35	0.21	0.11	0.38	0.18	0.46	0.23	1.93	<0.1	<0.1
	# Results above limit	3	3	1	3	3	3	2	2	0	0
	# Tests Performed	6	6	5	6	6	6	4	6	6	6
	Non-compliance cumulative (%)	50	50	41	43	45	46	46	44	39	35
BILL02100	Latest result (Max. Annual Value)	0.76	0.43	0.15	0.2	0.15	0.7	0.15	1.77	0.15	<0.1
	# Results above limit	2	2	2	4	2	4	1	1	1	0
	# Tests Performed	6	6	6	6	6	6	4	7	6	6
	Non-compliance cumulative (%)	33	33	33	42	40	44	43	38	36	32

4. CONCLUSIONS

Results obtained from the proposed tool gives a clear indication on how is the quality level of water resources. It helps reducing the uncertainty when the locations have low frequency of monitoring and few sample points, similar to the case of the Billings' dam. This tool could also support environmental assessments and efforts using public information available, to help population and environmental interests. Initially it will serve the population of researchers

who are concentrated on water issues and potentially could become a tool for public use to the people who use the untreated water in their day-to-day. This will also serve as an important tool for all people interested in monitoring the actual condition of water quality in the city they live, contributing to implement environmental programs and to increase the quantity of projects for prevention and recovery of water sources, ensuring the sustainability of water resources in the long term.

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