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Research Article

Water Resources in the Sao Paulo Metropolitan Area (RMSP): the underuse of Billings Reservoir

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Abstract

The aim of this paper was to highlight and analyze the factors that explain the underuse of the Billings Reservoir in the Sao Paulo Metropolitan Area, based on data that covered 5 years. This research was guided by hypothesis that the underuse is related to the pollution, due to domestic waste and/or non-household waste and garbage discharge. The method consisted of an evolutionary analysis of the Billings pollution levels and then on a dynamic and integrated analysis of the variables that support the hypotheses. Results showed that, in general, the Reservoir's water quality tends to worsen. In addition, the irregular garbage discharge into the Reservoir is still at high rates. In this sense, it was concluded that the variables analyzed (pollution levels, sewage, and garbage amount) provided favorable evidence for the confirmation of hypothesis. However, interviewees emphasized the membrane separation processes, such as ultrafiltration and nanofiltration, which together to other techniques may turn the water from Corpo Central (the most polluted area) fit for use. In other words, although pollution is the main problem, there are already modern technologies to treat such water.

Keywords: Natural Resources, Water Resources, Billings Reservoir, Underuse

1. Introduction

Natural resources are essential for the development of human activities, both for their survival and for their comfort. From the simple extraction of wood by a farmer on his farm to make firewood, to the complex refinement of oil by a large company, these are examples of the many and varied possibilities of natural resources. From the 2nd World War onwards, there was an increasingly accentuated demand for natural resources and this great demand culminated, however, in the 1970s, in a broad discussion on economic production and environmental conservation.

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The 1972 United Nations Conference on the Environment in Stockholm, or simply the Stockholm Conference, was a milestone in this debate. It drew the attention of the international community to environmental problems arising from the overexploitation of natural resources, which could compromise future generations. The Stockholm Conference, as well as other international meetings, also contributed to the consolidation of the concept of sustainable development in 1983, according to the report of the World Commission for the Environment (CMMAD) (RIBEIRO, 2001). According to the report, sustainable development "is that which meets the needs of the present without compromising the possibility of future generations meeting their own needs" (CMMAD,1988). In this way, natural resources came to be seen no longer as inexhaustible, but, in fact, as exhaustible.

In this context, water is also highly demanded, especially in densely populated areas. It is one of the most important components of the Earth, being essential in both biological and geological processes. As it is a vital liquid, humans, animals, and plants suffer in a few days if it is not ingested (approximately 70% of human beings' bodies are composed of water). It is indispensable for agriculture and for the maintenance of existing forests. Furthermore, it is a fundamental agent in the transformation of the planet's surface, modeling, for example, its morpho sculptures, whether by chemical and/or physical weathering, over geological time, in addition to promoting erosion (TEIXEIRA et al, 2009).

According to the Brazilian Institute of Geography and Statistics (IBGE, 2021), the Metropolitan Region of São Paulo (RMSP) has an estimated population of 22 million inhabitants. It is the most populous metropolitan region in the country, the 2nd largest in the Americas and the 10th largest in the world. It houses approximately 47% of the population of the state of São Paulo (46.6 million inhabitants) and around 10% of the total Brazilian population (213.3 million inhabitants).

According to the State Water Resources Plan (PERH), established by Law No. 7663/91, the water resources of the state of São Paulo must be managed based on the hydrographic basins. A total of 21 basins were defined. In this context, the RMSP is in the Alto Tietê Hydrographic Basin (BHAT), being the Water Resources Management Unit number 6 (UGRHI-6).

The UGRHI-6 is, when compared to all the other 21 UGRHIs in the state, the one that "has the lowest per capita water supply, totaling 130.68 m^3/year per inhabitant, due to its small geographic area and high population concentration" (SIGRH, 2017), in addition to being in a headwater region, that is, close to the springs. Therefore, the task of water supply in the RMSP can be challenging, to say the least.

The largest water reservoir in the RMSP is Billings. Designed by the American engineer Asa White Kenney Billings, the construction of the reservoir began in 1925 and its filling started in 1927. Originally, the reservoir was built to generate electricity for the city of

São Paulo through the Henry Borden plant, in Cubatão, and more recently, it has also been used to supply water to the population (EMAE, 2017).

The Billings Reservoir has a total storage capacity of around 1.1 billion m^3 of water (EMAE, 2017). However, only the Rio Grande branch and, more recently, the Taquacetuba branch are used for supply. According to the Basic Sanitation Company of the State of São Paulo (SABESP, 2017), the Braço Rio Grande produces about 5m3/s of water, supplying 1.5 million people in the municipalities of Diadema, São Bernardo do Campo and Santo André (only 7% of the entire population of the RMSP). The Taquacetuba branch began operating in 2000, through a transposition to the Guarapiranga Reservoir, being able to withdraw from it up to 4m3/s of water, when necessary. According to estimates by the Secretariat of Environment of the State of São Paulo (SMA, 2010) Billings would have the capacity to supply water to approximately 4.5 million people.

As previously mentioned, the RMSP has a lower per capita water availability than any other UGRHI due to its high population concentration. In this way, it is at least contradictory that so little use of the largest water reservoir available in the region, through only three of its branches: Rio Grande (112 million m^3 of total capacity and flow of 5 m^3/s of water) and Taquacetuba and Rio Pequeno (whose total capacities are not even possible to be estimated, as they do not have a dam separating them from the central body, being possible to withdraw from both 4 m^3/s of water, when necessary), totaling a flow of 9 m^3 /s, with the total capacity of the Billings Reservoir being 1.1 billion m^3 of water. For comparison purposes, the Cantareira System has a flow of 33 m^3/s and supplies 5.3 million people, with a total capacity of 982 million m^3 of water (SABESP, 2017).

In this sense, the aim of this research is to highlight and analyze the factors that explain the underuse of Billings Reservoir in the supply of the population in the Metropolitan Region of São Paulo, based on data that covered 5 years. To do so, this research was guided by hypothesis that the underuse is related to the pollution, due to discharge of domestic and/or non-domestic sewage, in addition to garbage.

2. Development

2.1 Billings Reservoir

The Billings Reservoir was designed by the American engineer Asa White Kenney Billings, having its construction started in 1925 and its filling started in 1927. The project was carried out by the former The São Paulo Tramway, Light and Power Company, Limited, with the objective of taking advantage of the waters of the Alto Tietê Basin to generate electricity at the Henry Borden Hydroelectric Power Plant, in Cubatão, through the unevenness of the Serra do Mar escarpment (EMAE, 2017).

Figure 1 – Construction of Pedreira Dam at the Rio Grande water course in 1928. Source: Capobianco & Whately (2002).

In the early 1940s, part of the waters of the Tietê River and its tributaries to Billings began to be diverted by reversing the Pinheiros River. This was possible thanks to the construction of the Pedreira and Traição Pumping Plants, in the late 1920s (CAPOBIANCO & WHATELY, 2002). (Figure 1,Figure 2).

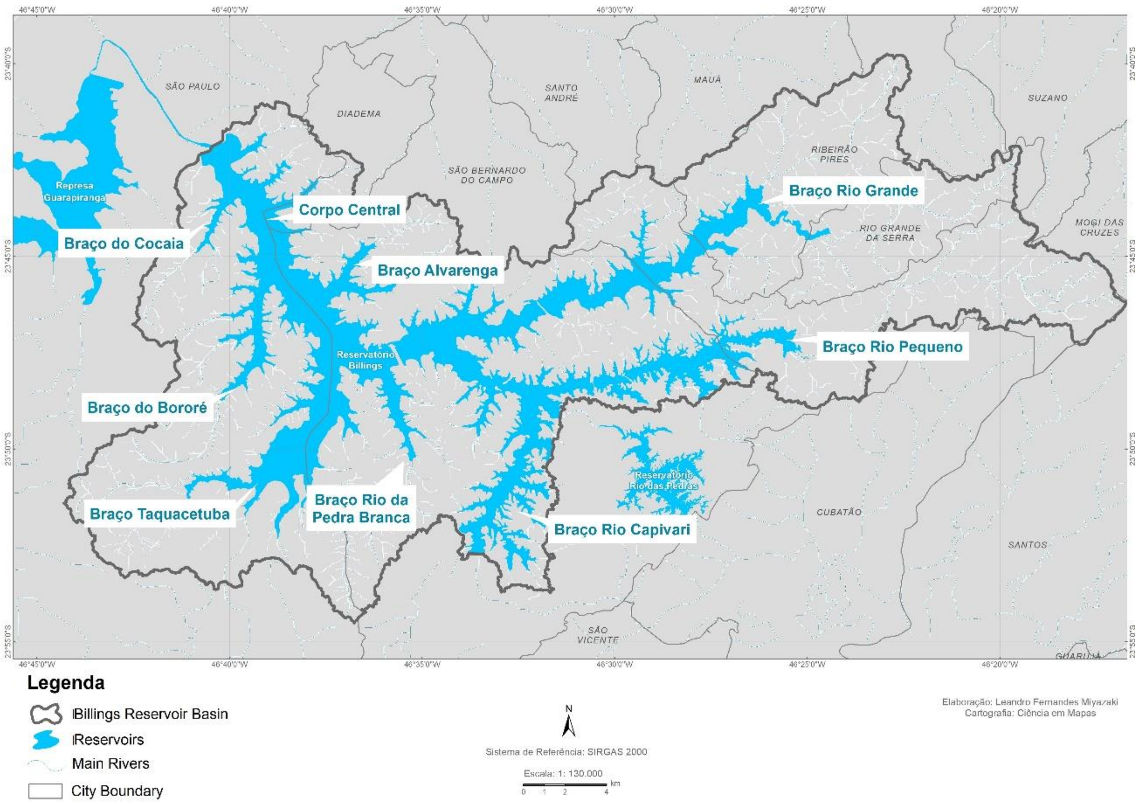

Figure 2 – Billings Reservoir River Basin and its arms (2018).

In addition, this operation also proved to be useful for controlling floods and the discharge of industrial effluents and sewage generated by the growing city of São Paulo.

However, in the early 1970s, this pumping began to have serious consequences at Billings, with CETESB starting the anaerobic stain removal procedures (CAPOBIANCO & WHATELY, 2002).

2.2 Pollution, Sewage and Garbage

In 1982, due to the large amount of sewage in Billings, it is performed the interception of Braço Rio Grande, through the construction of the Anchieta Dam, to guarantee the supply of the ABC Paulista (cities of Santo André, São Bernardo do Campo, and São Caetano do Sul). The worsening of the conditions of the dam led to increased pressure from environmentalists to stop pumping water from Pinheiros River to Billings (one of the most important river that crosses São Paulo) (CAPOBIANCO & WHATELY, 2002).

During the first meeting of the State Council for the Environment (CONSEMA, 1983), the Billings situation was addressed. The next year, part of the waters of the Tietê River returned to its natural course, and CETESB started working on monitoring the water quality in the Reservoir, intending to manage pollution through its natural purification capacity (CAPOBIANCO & WHATLY, 2002).

According to Capobianco & Whately (2002), the water quality in Billings is severely compromised, both because of the pumping of polluted water from the Pinheiros River, as well as the resuspension of contaminated sediments and the irregular human occupation of its watershed.

The social and economic condition of the population in the basin is predominantly precarious. The urban expansion of the metropolis through an intense process of the establishment of irregular settlements, led to the emergence of clandestine subdivisions, invasions, and communities, in increasingly distant areas and with a lack of good urban infrastructure (PDPA BILLINGS, 2010).

Figure 3 – Water from the also polluted Pinheiros River being pumped into Billings (left) and Irregular Settlements alongside the Reservoir (right). (Folhapress, 2015)

According to Capobianco & Whately (2002), the water quality in Billings is severely compromised, both because of the pumping of polluted water from the Pinheiros River, as well as the resuspension of contaminated sediments and the irregular human occupation of its basin (Figure 3).

The water characteristics of a reservoir are the result of a combination of several factors, including the nature ones, such as climatic cycles and ecological dynamics, or of an anthropic nature, such as irregular settlements being stablished in its surroundings, caused mainly by social exclusion (CAPOBIANCO & WHATELY, 2002).

In this way, the water concentration pollutants can be either due to external discharge, being dumped in the Corpo Central or in its tributaries, or by the internal discharge itself, through the resuspension of sediments contaminated by pollution. At Billings, the external discharge of pollutants consists of domestic and industrial sewage, in addition to garbage. On the other hand, the internal discharge is caused by the resuspension, as previously mentioned. The action of winds, rains or even a change in temperature causes the sediments to be moved in the water, causing the suspension of the accumulated pollutant discharges (CAPOBIANCO & WHATELY, 2002).

Figure 4 – Garbage discharged alongside the Reservoir. (Folhapress, 2015.)

Other factors of concern regarding the quality of Billings water are eutrophication, the concentration of heavy metals, the presence of pathogenic microorganisms and algae that are highly toxic. Eutrophication occurs due to the intensification of the concentration of substances that contribute to the excessive increase of aquatic plants and algae. Critical eutrophication is verified at the Cocaia, Bororé, and Rio Grande arms as well as in some points of Taquacetuba and Corpo Central. Heavy metals were also identified at several points at the Reservoir, such as the Corpo Central and Cocaia, Bororé, Pedra Branca, Rio Pequeno, Taquacetuba and Rio Grande arms, caused by pumping polluted water from

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Pinheiros River and the remobilization of sediments contaminated with metals from the Reservoir (CAPOBIANCO & WHATELY, 2002). (Figure 4).

3. Materials and Methods

3.1 Method

The method consisted of an evolutionary analysis of the Billings pollution levels and then on a dynamic and integrated analysis of the variables that supported the hypotheses.

3.2 Materials

3.2.1 Pollution Levels

To determine pollution levels were used the Raw Water Quality Index (IQA) and the Raw Water Quality Index for Public Supply (IAP). IAQ was based and adapted from a study from the National Sanitation Foundation (NSF, 1970). A quality score (q) is established, ranging from 0 to 100, for each of the 9 variables considered in this index. Each variable is weighted (w) in relation to its importance and, finally, IQA is obtained by multiplying each component (qw). The IAP is the weighting product between IQA and the Index of Toxic and Organoleptic Substances (ISTO) (CETESB, 2021).[1](Figure 5).

Raw Water Quality Index (IQA) and Raw Water Quality Index for Public Supply (IAP)		
Range	Class	
IQA ≤ 19		Poor
19 < IQA ≤ 36		Bad
36 < IQA ≤ 51		Regular
51 < IQA ≤ 79		Good
79 < IQA ≤ 100		Great

Figure 5 - Raw Water Quality Index (IQA) and Raw Water Quality Index for Public Supply (IAP).Source: CETESB (2021).

[1] For detailed variables explication see: https://cetesb.sp.gov.br/aguas-interiores/wp-content/uploads/sites/12/2021/09/Apendice-E-Indice-de-Qualidade-das-Aguas.pdf.

3.2.2 Total Amount of Domestic and/or Non-domestic Sewage and Garbage

To determine the Total Amount of Domestic and/or Non-domestic Sewage was used the Sewage Collection and Treatability Index of the Municipality's Urban Population (ICTEM) (Figure 6), which portrays a situation that takes into account the effective removal of the biochemical oxygen demand (BOD), in relation to the potential BOD generated by the urban population without, however, failing to observe the importance of other elements that make up a sewage treatment system, such as the collection , removal and treatment. The indicator makes it possible to transform the nominal values of BOD into values for comparison between different situations in the various municipalities, reflecting the evolution or state of conservation of a public sewage treatment system. To determine the amount of garbage were consulted articles from the most reputed magazines in Brazil.

Sewage Collection and Treatability Index of the Municipality's Urban Population (ICTEM)		
Range	Class	
ICTEM ≤ 2,5		Poor
2,5 < ICTEM ≤ 5,0		Bad
5,0 < ICTEM ≤ 7,5		Regular
7,5 < ICTEM ≤ 10,0		Good

Figure 6 – Sewage Collection and Treatability Index of the Municipality's Urban Population (ICTEM). Source: CETESB (2021).

3.2.3 Interviews

Interviews were conducted with experts in the field, PhD professors from the Department of Hydraulic and Environmental Engineering at Escola Politécnica da USP.

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4. Results

4.1 Pollution Levels

Data were collected and analyzed for the period from August 1, 2012 to August 1, 2017. For the IQA and IAP Indexes the following water quality monitoring points (Table 1,Figure 7) were considered:

Table 1 – Water Quality Monitoring Points at the Billings Reservoir (2017).

Water Quality Monitoring Points							
Point Code	**Water Resource**	**UGRHI**	**City**	**For Supply?**	**Latitude**	**Longitude**	**Operating Since**
BILL 02030	Billings Reservoir	6	SÃO PAULO	No	234304	463951	1/1/2007
BILL 02100	Billings Reservoir	6	SÃO PAULO	No	234457	463852	1/1/1999
BILL 02500	Billings Reservoir	6	SÃO BERNARDO DO CAMPO	No	234727	463554	1/1/1976
BILL 02900	Billings Reservoir	6	SÃO BERNARDO DO CAMPO	No	234904	463123	1/1/1976
BIRP 00500	Arm Rio Pequeno	6	SÃO BERNARDO DO CAMPO	Yes	234728	462814	4/14/2015
BITQ 00100	Arm Ribeirão Taquacetuba	6	SÃO PAULO	Yes	235041	463920	1/1/1999
RGDE 02200	Rio Grande Reservoir	6	RIBEIRÃO PIRES	No	234423	462644	1/1/1983
RGDE 02900	Rio Grande Reservoir	6	SÃO BERNARDO DO CAMPO	Yes	234616	463203	10/1/1974

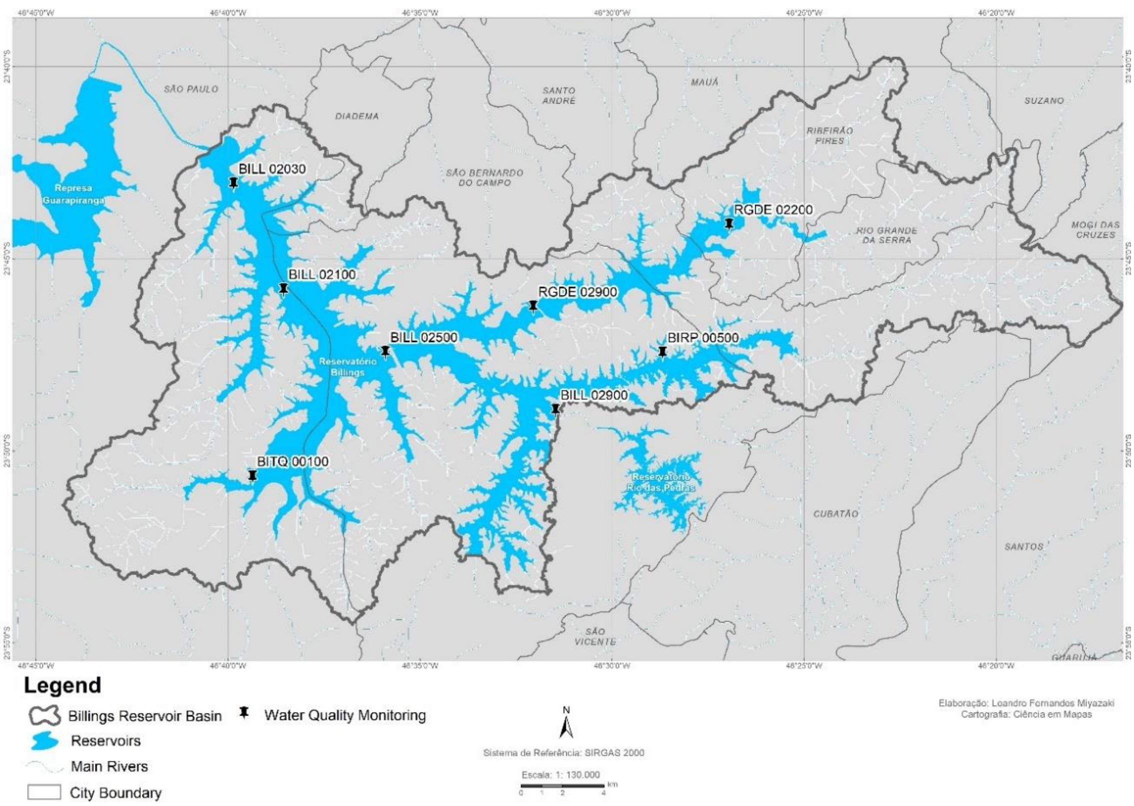

Figure 7 - Water Quality Monitoring Points at the Billings Reservoir (2017).

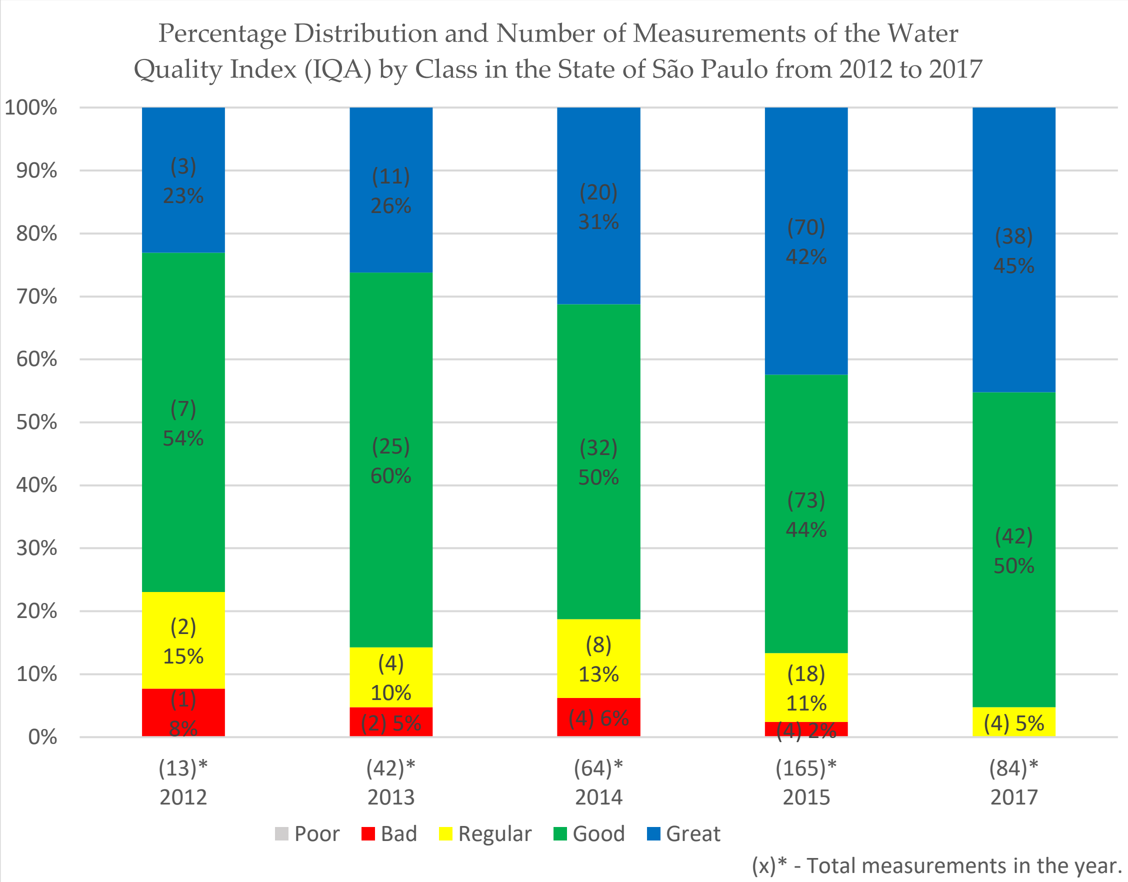

Figure 8 - Percentage Distribution and Number of Measurements of the Raw Water Quality Index (IQA) by class at the Billings Reservoir from 2012 to 2017. Source: InfoÁguas (2017).

Figure 8 shows that water quality was predominantly classified as Good or Great, increasing the Great class from 23% in 2012 to 45% in 2017. In addition, the Poor class was not verified at any time, while the Bad class dropped from 8% in 2012 to 2% in 2015, not being verified in the 2017 measurements. In general, there was an overall improvement on the water quality.

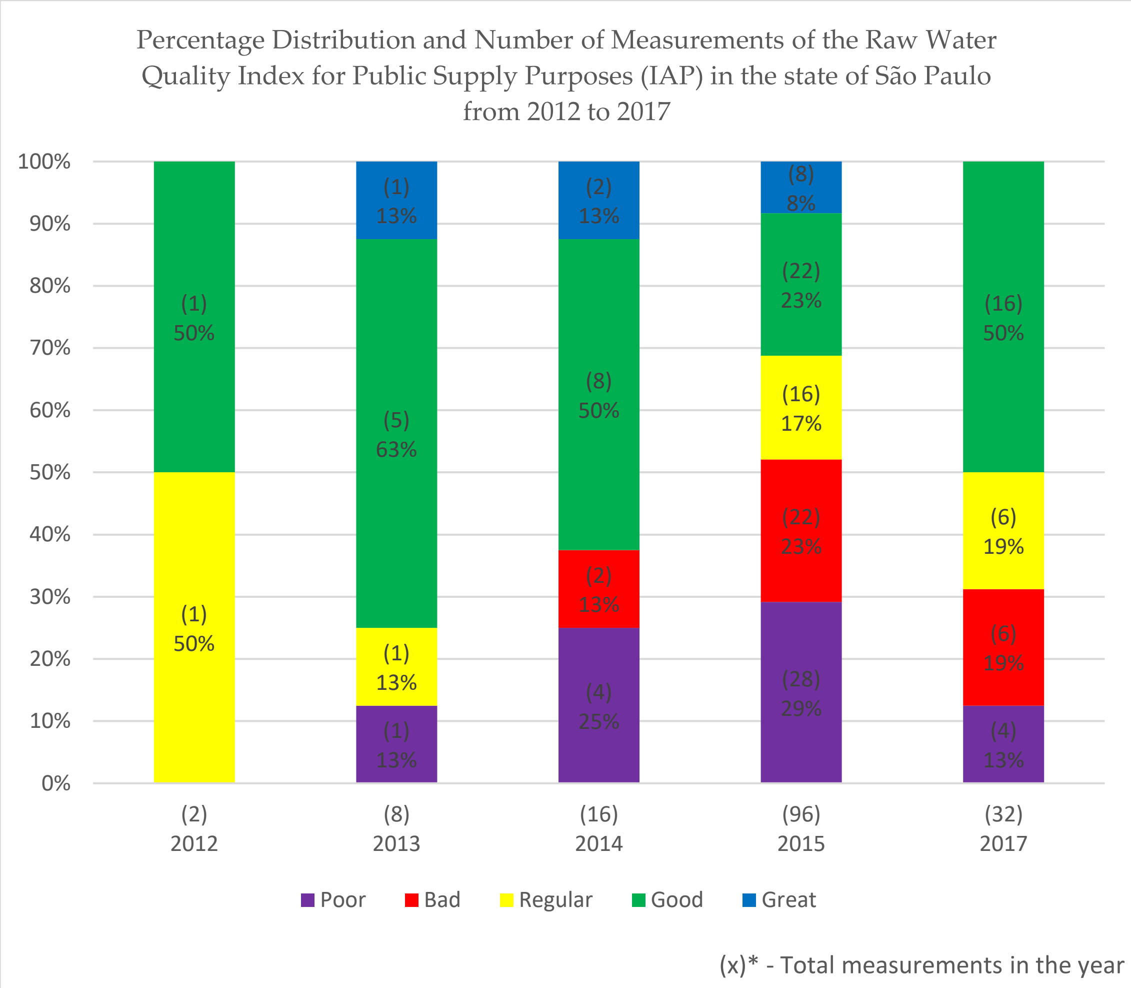

Figure 9 - Percentage Distribution and Number of Measurements of the Raw Water Quality Index for Public Supply (IAP) by Class in the Billings Reservoir from 2012 to 2017. Source: InfoÁguas (2017).

Figure 9 shows that there was great variation in the IAP classes. In 2012, despite not appearing the classes Poor or Bad, it is important to highlight that there were only two monitoring points, thus being a very restrictive result quantitatively. As of 2013, the total of monitoring points increased to 8, with most of them - 63% - presenting water quality as Good. Between 2013 and 2015, a deterioration in the quality of the IAP is observed (the Poor class goes from 13% to 29%), in addition to an increase in the number of monitoring points (from 8 to 96 in total). In general, the IAP index showed a worsening trend between 2012 and 2015, but in 2017 it showed some improvement (50% of the points were from the Good class).

4.2 Total Amount of Domestic and/or Non-domestic Sewage and Garbage

Table 2 shows that Diadema, Santo André and São Paulo have the highest rates of sewage collection among the cities at the Billings Basin. Ribeirão Pires and Rio Grande da Serra have the lowest rates, with the latter collecting less than half of its effluents. However, despite owning the best collection rates the cities of Diadema and Santo André are the ones with the lowest treatment rates. When it comes to the efficiency of the effluent treatment process, all of them present rates above 80%.

Table 2 - Collection, Treatment and Efficiency Rates of the Sewage Network of the Municipalities inside the Billings Basin – 2016. Source: CETESB (2016).

Collection, Treatment and Efficiency Rates of the Sewage Network from Cities at the Billings Basin - 2016				
City	Urban Population	Atendimento (%)		Efficiency (%)
		Collection	Treatment	
Diadema	415,180	90	30	91
Ribeirão Pires	121,130	70	70	91
Rio Grande da Serra	48,861	49	85	91
Santo André	712,749	98	41	98
São Paulo	11,910,639	88	75	82

Table 2 - Collection, Treatment and Efficiency Rates of the Sewage Network of the Municipalities inside the Billings Basin – 2016. Source: CETESB (2016).

Table 3 shows that BOD and Urban Population are directly proportional variables, as the greater the population, the greater the BOD produced. Diadema (75%), Santo André (63%) and Rio Grande da Serra (61%) shows the highest remainder amount, being classified as Bad. Ribeirão Pires (55%) and São Paulo (46%), are classified as Regular and Good, respectively. Despite the largest population, the Good rate for São Paulo mean higher investments due to social and political pressure, since its magnitude results in stronger institutions. As the treatment rates do not follow the collection ones, the result is a lower rate in ICTEM.

Table 3. Sewage Collection and Treatability Index of the City's Urban Population (2016

Sewage Collection and Treatability Index of the City's Urban Population (2016)				
City	Urban Population	BOD (kg/per day)		ICTEM
		Potential	Remainder	
Diadema	415,180	22,420	16,926	3.39
Ribeirão Pires	121,130	6,541	3,621	5.20
Rio Grande da Serra	48,861	2,638	1,630	4.50
Santo André	712,749	38,488	24,475	4.75
São Paulo	11,910,639	643,175	296,486	6.45

Table 3 – BOD and ICTEM from Cities at the Billings Basin – 2016. Source: CETESB (2016).

Figure 10 – Irregular settlements at the deactivated landfill Alvarenga in 2016 and Alvarenga landfill in the early 2000.

Figure 10 shows the Alvarenga landfill, a 40,000m^2 area that was used for the discharge of heavy industrial waste and irregular debris for many years. According to the PDPA Billings (2010), since the establishment in 1972 to nowadays more than 2 million tons of garbage have been discharged in it. Although deactivated, it is estimated at 400 tons of garbage[2] being discharged every day at the Billings Basin. Besides this, the new irregular settlements at this area (result of weak housing policies) potentiates the pollution levels at the Billings basin.

4.3 Interviews

Questions like 'Why the water from the Corpo Central is not treated for supply' (the most polluted area) and 'Is there a technique available to treat water from the Corpo Central for supply' were asked. Answers mentioned that membrane separation processes, such as ultrafiltration and nanofiltration, can remove various contaminants present in the water and do not require chemical products continuously for their operation, which eliminates the generation of sludge. Photochemical oxidation process, which can eliminate organic pollutants such as residuals from drugs and other chemicals, can be used for complementary treatment (MIERZWA, 2018)[3].

Also, were asked questions such as 'If there is a technique available for treating the water from the Corpo Central, why it is not used?' and 'Would you like to add something that was not covered? Answers mentioned that reasons may rely on mainly due to the lack of knowledge about its potential compared to conventional water treatment technologies, as well as a misguided view of its implementation cost. It was pointed out that many people even those who work on this subject believe that bringing water from far away is cheaper than using this kind of technology. To wrap up, the interviewees added that problems related to water supply in highly urbanized regions are quite complex and require concerted actions to address them. Variables as reduction of water

[2] Veja Magazine (2015).
[3] PhD Professor at the Department of Hydraulic and Environmental Engineering at Escola Politécnica from University of Sao Paulo.

consumption, adoption of modern technologies for water treatment, expansion of sewage collection and treatment (MIERZWA, 2018) as well as the lack of interest of decision makers who prefer to import water from distant basins at high costs (HESPANHOL, 2018) [4]were brought up too.

5. Conclusion

IQA Index which was considered to provide an overview of water quality showed an improvement trend between 2012 and 2017. However, measurements for 2016 were not located to be analyzed. IAP Index, the most reliable index, was considered to have the quality of water for public supply purposes. In general, despite the variations in the number of measurements per year during the analyzed period (from only 2 in 2012, rising to 96 in 2015), it was possible to verify that the water quality has a worsening trend. In 2017, there was a fall again in the number of measurements points (32 in total), but when compared to 2015 (which had presented the worst rates) there was a fair trend of improvement. Data for 2016 was also not found to be analyzed.

BOD and Urban Population are directly proportional variables, as the greater the population, the greater the BOD produced. Regarding the performance of sewage collection and treatment systems (ICTEM), only São Paulo presented an index classified as Good. Ribeirão Pires was classified as Regular while Santo André, Rio Grande da Serra and Diadema were classified as Bad. This is a result, on the one hand of the low rate of sewage collection in some cities, such as in Rio Grande da Serra, and, on the other hand, of the low rate of treatment, such Diadema and Santo André. Thus, it is necessary that the collection and treatment rates go together, as this is the only way to have an effect. It is estimated that 400 tons of garbage is still discharged into Billings. Although Alvarenga landfill is officially deactivated its remediation has not started and the new irregular settlements potentiates the pollution levels.

In this sense, it was concluded that the variables analyzed (pollution levels, sewage, and garbage amount) provided favorable evidence for the confirmation of hypothesis. However, interviewees emphasized the membrane separation processes, such as ultrafiltration and nanofiltration, which together to other techniques may turn the water from Corpo Central fit for use. That means that the pollution is the main problem, but it is already possible to overcome this obstacle. For future research, it is recommended to explore the status quo around this subject to better understand these dilemmas.

[4] Late PhD Professor at the Department of Hydraulic and Environmental Engineering at Escola Politécnica from University of Sao Paulo. Founder of the International Reference Center on Water Reuse (CIRRA).

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