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## Chapter

# Environmental Monitoring of Water Quality as a Planning and Management Tool: A Case Study of the Rodrigo de Freitas Lagoon, Rio de Janeiro, Brazil

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## Abstract

The Rodrigo de Freitas Lagoon is an urban water body, representing one of the most popular spots for the local community. It underwent serious environmental degradation, at first through its water mirror reduction and more recently through sewer inflows. Concurrently, the difficulty in renewing the water combined with adverse climatic conditions has repeatedly led to an alarming fish mortality rate. The monitoring of its water quality has been carried out as a management and planning tool that lead to the improvement of the environmental conditions. This study seeks to assess monitoring results by correlating the factors that might be the cause of a failure to comply with environmental regulations. Although it is evident that particular places in the Lagoon might be more often affected by illegal sewer discharges, no evidence could be found of any variations between the six sampling points. However, the rise in the levels of *Escherichia coli*, nitrogen and phosphorus, and the general temperature conditions, pH, and salinity of the water shows that the most significant alterations occurred in spring 2018. The complexity of the period of phytoplankton growth followed by the fish mortality from anoxia underlines the need for monitoring as a tool for a better understanding of the alterations, providing guidance with regard to the planning and management of the ecosystem.

**Keywords:** coastal environment, water resource management, environmental impact, water quality monitoring, fish mortality

## 1. Introduction

The Rodrigo de Freitas Lagoon (LRF) is a permanent area of leisure for the inhabitants of Rio de Janeiro and the site of important rowing and canoeing competitions such as those of the 2016 Olympic Games—it is one of the picture postcard panoramic scenes of the “Wonderful City.” As well as its topographical features, this region includes parks, areas for sport, a skating rink, a heliport, a path

for walking, and a cycle track; in effect, it is one of the main tourist centers in the city and famous for its landscapes.

The LRF has been suffering from the environmental effects of anthropic activities which have been practiced for decades, including the inputs of organic matter responsible for phenomena such as the constant eutrophication of the water bodies [1]. Rosso [2] suggests that the main culprits of the problems that have been detected are the intense urban occupation of the hydrographic basin, together with the growth of anthropic activities and a lack of compliance with elementary standards of urbanism or the basic regulations for environmental sanitary conditions such as sewage systems and urban drainage.

In view of its importance, the LRF has become a frequent target of controversy with regard to the quality of its water. More recently, the Lagoon has given way to speculation about whether it could be safely used for the rowing and canoeing events in the Olympic Games, in a way that would not put the competitors at risk. However, after a period of delay and heated debate with specialists being consulted and other interventionary measures, the events went ahead as planned without causing any subsequent problems.

The LRF has attracted a good deal of concern because of its valuable socio-economic and environmental attributes and its great exposure in the national and international media with regard to the quality of its waters. The Lagoon is widely used by the public, and this includes recreational activities of a secondary kind or, in other words, activities in which contact with the water is sporadic or accidental and there is little likelihood of ingesting it. It is also used by traditional fishermen whose subsistence has depended on it for many generations.

As in the case of Fonseca and Santoro [3], as well as other lagoons along the coast of the State of Rio de Janeiro, the LRF has aroused interest among academics owing to the extent to which it has undergone adverse natural phenomena such as stagnation and the deterioration of the quality of its water, the release of gases, silting, and the huge fish mortality rate.

The poor circulation and renewal of the waters of the Lagoon mean that the seawater which enters in small quantities and at a slow speed in its depths—where it is more dense—becomes anaerobic in a short time and full of gases, and this is further aggravated by the oxidation of the already present organic matter [4, 5]. The existence of natural barriers like Piraque Island, on the east shore, and Caicaras Island, on the south shore, underlines the difficulty faced by the Lagoon in being regularly replenished by the affluent rivers and the entry of water from the sea.

Several interventions have been made, in particular over the past few years, with a view to improving the environmental conditions of the Lagoon. These include the following: (a) a greater degree of surveillance with regard to the construction and irregular waste disposal in the sewers and drainage system, (b) the improvement of the alteration and renewal of the waters by adhering to stricter standards, and (c) forging a better link with the sea through the Jardim de Allah (Garden of Allah) Canal and its respective floodgate. A comprehensive environmental monitoring system was also installed which was based on frequent analyses of various physicochemical and bacteriological parameters at strategic points placed along the Lagoon; this formed a solid database for the support of decision-making, as well as the management and planning of preventive and control measures.

The objective of this research study is to analyze the data from the environmental monitoring which was carried out in the LRF. The purpose of this is to determine the conditions of the quality of the water that is not in compliance with the regulatory standards, as well as the failure to adhere to these parameters, especially with regard to the limits of CONAMA 357/05. On the basis of this analysis, the aim is to relate these failures to the occurrence of environmental degradation and anthropic activities, as well as the

managerial and operational shortcomings with regard to the Lagoon. Some measures are recommended to mitigate these adverse effects and improve the environmental conditions of this vital and emblematic hydric body in the city of Rio de Janeiro.

The chapter is divided in a way that can make it easier to discuss and reach a conclusion about the results obtained from monitoring the quality of the water in the LRF. It sets out by characterizing the features in the area under study and reflecting on the environmental monitoring that is carried out. Following this, there is a methodological description and examination of the implications of the analyses conducted of the water in the Lagoon through physicochemical and biological data.

## **2. General characterization of the scope of the study**

### **2.1 Relief, hydrography, and vegetable coverage**

The Rodrigo de Freitas Lagoon is situated in the southern zone of the city of Rio de Janeiro, between two mountains (Sumare and Corcovado) and the seafront of Ipanema, and is also bordered by the districts of Humaita and Gavea. With an area of 32 km<sup>2</sup>, its drainage basin covers a large part of the districts of Gavea, Jardim Botânico (the Botanical Gardens), Ipanema, and Leblon, including the Lagoon, which necessarily serves as a storage basin in the periods of heaviest rainfall. The LRF has a water feature of about 2.2 km<sup>2</sup>, a perimeter of 7.8 km, and an average depth of the order of 2.80 m, with a maximum of 4.0 m and a volume of approximately 6,200,000 m<sup>3</sup> [6]. It was noted that after the sand removal works that were carried out on the bed of the Lagoon during the period preceding the Olympic Games in 2016, some parts showed a greater depth than 4.0 m.

The LRF is replenished by the rivers that flow down from the surrounding slopes and currently this water is salubrious. The main rivers concerned are the Rios dos Macacos e Cabeça (Rivers of the Monkeys and Head) which flow into the Lagoon through the Rua (Street) General Garzon Canal and River Rainha (Queen), which is currently being diverted by the Avenida Visconde de Albuquerque Canal (**Table 1**) [7].

The interconnection of the Lagoon with the sea is being effected by the Jardim de Alah, a man-made canal which is 800 m long and has a width which ranges between 10 and 18 m, although one section of its depth is 0.70 m (**Figure 1**). The RIOAGUAS Foundation is responsible for controlling the level of the water feature of the Lagoon by operating the sluices in the canals of the Jardim de Alah, from Visconde de Albuquerque and General Garzon, with a view to improving the environmental conditions of the LRF and the bathing in the Ipanema and Leblon beaches.

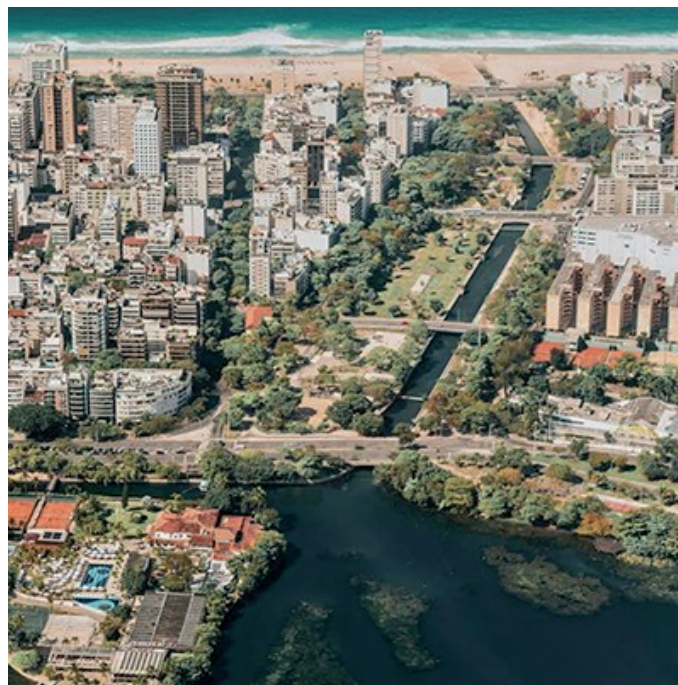
TECMA (Environmental Technology) [8] states that it is essential to take note of the rivers and canals linked to the Rodrigo de Freitas Lagoon to obtain a full understanding of its complexity, insofar as any alteration in the quality or volume of the inflow system can affect the dynamics of these waters.

Serious flooding has been recorded in the region, especially in the less steep areas of the basin that are closest to the water feature of the Lagoon—such as in J. Botânico. This occurs during periods of heavy rainfall, together with a rise in the water level of the LRF. At these times, the floodgates of the Jardim de Alah Canal are opened, to allow the outflow of water to the sea, as well as the floodgates of the General Garzon Canal, with the aim of preventing the overflow of the water of this canal and hence extensive flooding in the surrounding area. However, this management of the sluices of CGG is only undertaken as a secondary strategy when the outflow of the water to the sea through the floodgates of the Visconde de Albuquerque Canal is not a sufficient response to the crisis [11].



Water course	Drainage area (km <sup>2</sup> )	Hydrographic conditions	Districts that have been drained
Rio Cabeça	1.9	Flows from the foothills of Morro do Corcovado, in sections of 520 m, and is drained in the Av. Lineu de Paula Machado Canal which in turn issues from Rio dos Macacos, on the stretch along the Rua Gal. Garzon	Jardim Botânico
Rio Macacos	7.2	Flows from the foothills of the Queimado Sumaré mountains, in sections of 520 m, and is diverted in its final stretch, from Rua Gal. Garzon to the Canal of the Jockey Club	Alto da B. Vista, Horto e Botânico
Rio Rainha	4.3	Flows from the southern slopes of Serra da Carioca, with paths of 680 m, and is drained into the da V. de Albuquerque Canal	Gávea

**Table 1.**  
*Features of the hydrographic basin of the Rodrigo de Freitas Lagoon [9].*



**Figure 1.**  
*Connection of the Lagoon with the sea through the Jardim de Alah Canal [10].*

## 2.2 Population and socioeconomic factors

The LRF lies within the borough of the Lagoon and is situated in a region with a community that has a high purchasing power, with the exception of some local people who have informal occupations and whose houses lack a separate drainage system. Three of these areas are well known and stand out: (i) the irregular occupation in the area located at the end of the Rua Pacheco Leao, alongside the Jardim Botânico; (ii) the housing complex called Cruzada Sao Sebastiao, situated close to the Jardim de Alah; and (iii) the community in the area situated at the end of Rua Viuva Lacerda, near to Rua Humaita, in the district with the same name.

Soares et al. [1] provide the census for 2000 which showed that the population consisted of 18,221 inhabitants with 6652 households, while in 2010 this had risen to 21,198 inhabitants and 9361 households (when restricted to the area surrounding the Lagoon). The data provided by IPPUR and IBGE [12] suggest that the region (Macrozona VI-Lagoon) has a demographic density of 119.18 inhab/ha, which corresponds to 2.97% of the total population of the municipality.

Feature	Data	Source
Drainage basin área (km <sup>2</sup> )	32	INEA [6]
Water feature (km <sup>2</sup> )	2.2	INEA [6]
Perimeter (km)	7.8	INEA [6]
Average depth (m)	2.80	INEA [6]
Volume (m <sup>3</sup> )	6,200,000	INEA [6]
Districts	Ipanema, Leblon, Gávea, J. Botânico, Humaitá e Lagoa	RIO DE JANEIRO [10]
Population (inhab/number of households in 2000)	18,221/6,652	Soares et al. [1]
Population (inhab/number of households in 2010)	21,198/9,361	Soares et al. [1]
Demographic density (inhab/ha)	111.18	IPPUR and IBGE [11]
% of total population of the municipality of RJ	2.97%	IPPUR and IBGE [11]
IDHM	0.959–0.970	SEBRAE [12]

**Table 2.**  
*General data concerning the LRF and its surroundings.*

According to the data provided by SEBRAE [13], based on figures published by IBGE, the IDHM of the region ranges from 0.959 (Lagoon) to 0.970 (Ipanema), which are situated at the two highest points in the municipality. This represents a highly valued region of the city with high-rise buildings of a good standard, diversified trading practices, services, and leisure activities, including the shoreline of the Lagoon which is provided with clubs, beaches, bars, beach huts, and various tourist activities.

According to the portal of RioTur [14], some of the most expensive buildings in Rio can be found in this region: in its ranking in the real estate market, the district is second only to Leblon. RioTur also states that at weekends, the three parks that encircle the picture postcard panorama—Patins, Taboas, and Cantagalo—are visited by 120,000 people in search of leisure and relaxation, where they are served by 15 food bars. **Table 2** shows some general features of the LRF and its surroundings.

### 2.3 Use and occupation of the soil

The layout for the occupation of the region can basically be divided into three separate typologies. The first are areas with little or no occupation and linked to regions that are densely forested with steep slopes and form a part of (or are close to) the Forest of Tijuca. These places are difficult to reach, and the construction of allotments and new buildings is impeded by the environmental conditions of the area. There are some large areas with good vegetable coverage such as Parque Lage and Jardim Botânico that are nearby.

The second typology for land use is linked to a large area of low occupation and includes areas of social interaction and recreation such as the numerous squares (Santos Dumont Square and others), the waterfront of the Lagoon (Patins and Catacumba Parks), as well as the extensive area of Gavea and Hipica Racecourse.

The third typology encompasses the buildings (including various commercial and residential properties), shopping centers, schools, public roads, and sidewalks where the degree of urbanization and waterproofing protection is much greater than in the first two typologies.

Urban growth, particularly informal settlements, have aggravated the problem of organic matter being dragged to the Lagoon, which, owing to a lack of investment in sanitary sewage systems in the last 30 years, has led to a very serious situation with regard to the effects of drainage on the water body [7].

## **2.4 Traditional environmental problems in the LRF**

Traditionally, both the LRF and its surroundings have been densely populated in recent decades, and this urbanization has been accompanied by several harmful environmental effects, such as those arising from numerous landfills and silting that have sharply reduced its water features. According to Soares et al. [1], at the beginning of the 1970s, there occurred a spate of particularly aggressive property speculation in the district surrounding the Lagoon, which had experienced landfills since 1808 and lost almost a half of its original area. Despite the fact that Municipal Decree 130/1975 had stipulated the boundaries of the surface area of the water features, it was only finally protected definitively by Decree 9.396/1990.

Another serious impact, which is still prevalent, is closely bound up with the continuous discharges of sanitary effluent into its waters. This is generally caused by illegal sewerage networks for the rainwater drainage system that pours into the Lagoon and the affluent rivers and canals [15]. For this reason, the quality of the water of LRF greatly deteriorated in the period 1970–2000, as a result of the installation of drainage pipes, through the water supply system, as well as through contact with the tributaries of the rivers that contained a considerable polluting load when they reached the entry of the floodgates of the General Garzon Canal [6, 16].

For several years, the situation was aggravated by the presence of two craters at the bottom of the Lagoon: one between the Caicaras and Flamengo Clubs and the other in front of Cantagalo. These depressions arose from the withdrawal of material for landfills and led to the accumulation of a good deal of organic matter in anaerobic decomposition, where it produced toxic gases such as sulfidic ores and methane. It was found that the pit that was less deep (Caicaras) was completely filled with silt sediment at one part of the bed of the Lagoon. This discovery was made in the period preceding the Olympic Games of 2016, when an attempt was made to attain a minimum depth of 3 m in the whole region used for the competition. With regard to the deepest pit (Cantagalo), there is no information about its current depth, because no bathymetry was employed after these proceedings. Mello [17] states that the filling of the pits could be regarded as a positive effect of the silting mentioned above, since it could operate as an anaerobic biodigester and lead to an increase of the area of water circulation (albeit on a small scale).

### *2.4.1 Evolution of fish mortality in the LRF*

The first studies on the stagnation of the water and the mortality of fish in the LRF were reported in 1877 by the Baron of Lavradio and in 1880 by the Baron of Teffe. According to a survey carried out by Andreata [18], there are about 60 species of fish in the LRF and, hence, different degrees of sensitivity and tolerance to a wide range of factors such as temperature, dissolved oxygen, pH, and salinity.

The mortality rate of the fish recorded in the Lagoon can mainly be attributed to the following causes: a lack of renewal of the waters, algae toxicity, the disposal of wastewater, the stirring up of soil, and the anoxic sediment layer at the bottom [1]. It has been argued that the serious problem of the mortality rate of the fish in the Rodrigo de Freitas Lagoon was not caused by the installation of a sewage system but rather by the current stock of nutrients that can be found today which result from a combination of the older sewage systems *in natura* and the rainfall drainage and



the fact that there is an ineffective outlet to the sea [19]. However, what has been observed by the monitoring is that the influence of the sewage system is essential for the nutritional intake in the Lagoon [17].

The entry of this organic load as well as the stirring up of the sediment at the bottom has made available a large number of nutrients for the water column. This can allow algae to flourish and lead to phenomena of natural or anthropic origin which can be defined as an explosive growth that is self-limiting and confined to just one or a few species of microorganisms [20].

Lima [5] notes that even gentle breezes can prevent the stratification of the water column and lead to the horizontal uniformity of the water mass. He stresses the fact that, when in a condition of instability, the ecosystem in question is more vulnerable at nighttime since at this time there is no primary production (i.e., photosynthesis), but only the absorption of oxygen that is dissolved through respiration.

There is no doubt that the situation in the LRF has improved, as can be confirmed by the reduction in the mortality rate of the fish. This improvement has also been demonstrated by the results of the analyses conducted to monitor the quality of the waters of the LRF and also by the decreasing rates of the parameters such as mortality and DBO shown by CEDAE itself. The Sustainability Management Plan for the Olympic Games in Rio (2016), published in 2013, recorded an improvement in the quality of the water. However, the situation is still far from being effectively remedied, and these mass deaths continue to occur, although they are less frequent than was found in the past, as explained above.

## **2.5 Urban infrastructure**

The region is served by infrastructural facilities of a good standard which include telephones, electricity, a transport system and a road network (with streets and a cycle path), a water supply system, a public drainage system, and sanitary sewage system, as well as a completely separate system operated by CEDAE. Nonetheless, it is still possible to find polluted water being discharged into the Lagoon through a network of drains and through the rivers that flow into the LRF, even in periods of serious drought. Thus, it can be proven that there is still a link between the public sewerage system and the installation of drains in the streams themselves. These installations end up by reaching and polluting the water in the rivers and the Rodrigo de Freitas Lagoon itself. This is the case, for example, of the pollution witnessed in the Macacos Canal, which is connected to the river with the same name, as well as the Rainha and Cabeça rivers, before flowing into the Lagoon.

On the basis of the analysis conducted by INEA [6], the Macacos River was found to be in an excellent condition above the Forest of Tijuca but began to be extremely polluted after it had passed the Jardim Botânico. The analysis of its water revealed that at certain times the Macacos River records a high level of pollutants. Researchers and officials at the Jardim Botânico found that some animals had symptoms of diseases that could be linked to this pollution and contaminated water.

According to Bess D'Alcântara et al. [15], the occurrence of problems in the sanitary sewage system in the LRF basin resulted in large amounts of waste in the water feature of the Lagoon, which further impaired the indicative parameters of the quality of its waters.

### *2.5.1 System of culverts for the LRF protection*

In recent years, the region has been the object of several projects and public measures aimed at reducing, or even eradicating, this problem of wastewater and hence improving the environmental conditions of the Lagoon. These include an



increase in inspection, carrying out awareness programs among the public and detecting and removing the illegal systems. The last measure taken of any great significance was the building of culverts around the Lagoon, which began in 2001.

Further expansionary work was undertaken by CEDAE in 2009 and included reforming and broadening the sanitary sewage system of the region and adapting it to several lift stations, as well as capturing the effluent discharged irregularly in the drainage system during the dry season. Together with the sewage from the separate system, the effluent captured is currently being canaled to the submarine pipeline of Ipanema.

The expansion of the culverts took place in the stretch of water from the shore of Leblon along the Jardim de Alah Canal and envisaged only three of the 12 points of the rainwater drains that were identified in the canal—the system came into operation in the second semester of 2016. The incorporation of these points took account of their recurrent signs of pollution from sanitary effluent. As a result of this intervention in the CJA, the final destination of the sewage which could perhaps be found in the culverts of rainwater began to be the submarine pipelines of Ipanema. However, there are still reports of the overflow of effluent in this stretch of water, which suggests that the operation of the CJA culvert is not suitable, even in periods of drought. The daily inspections carried out by the RIOAGUAS Foundation to detect signs of effluent through the chemical reagents of *Nessler* often recorded positive results for the presence of recent sewage in the samples at the key points of the drainage system.

Bess D'Alcântara et al. [15] state that the system of culverts is based on measures taken in periods of drought—these structures were of a provisional character and designed to collect sewage discharged irregularly in the rainfall drainage system as an emergency measure. The absence of any long-term planning and lack of financial investment to curb the use of illegal pipelines changed the “catchment hydrology in periods of drought” into definitive units. As a result, the initial benefits of their installation have been wiped out by the worsening of the operational situation and become one of the factors that add to the vulnerability of the system. Bess D'Alcântara et al. [15] also argue that the contribution made by rainfall to the system is a key factor and indicator of this vulnerability since it is not foreseen in the Brazilian standards for a sanitary sewage system of a completely separate type, as this is regarded as unsuitable and unauthorized. The contributions made by rainfall (mixed with the sewage system that involves illegal pipelines) are responsible for the main overflows from the culverts which have the Rodrigo de Freitas Lagoon as their final destination and further worsen the quality of its water feature.

## 2.6 Institutional aspects and management

The Rodrigo de Freitas Lagoon covers a Permanent Protected Area that is regulated by the Organic Law of the municipality of Rio de Janeiro, as stipulated in Article 463 of 2008, and has had its water feature protected since the 1990s.

The management of LRF involves a wide array of skills and public bodies in particular INEA, CEDAE, RIOAGUAS, and SMAC, the last two of which form a part of the structure of municipal governance. **Table 3** shows the main public bodies involved. The activities of the policymakers cover a number of areas such as projects, public works, inspection, maintenance, and the monitoring of the Lagoon and its surroundings.

Although the responsibility for managing the water bodies lies with the States, the National Policy of Hydraulic Resources, instituted in 1997, explicitly recommends the effective participation of the municipalities in the local environmental management, while the significant need for the planning and management of the

<b>Public agencies/ companies</b>	<b>Level of governance</b>	<b>Main attributions</b>
RIOAGUAS Foundation	Municipality of RJ	Construction, operation, and monitoring of the public rainwater systems; daily inspections and monitoring of the rainfall/runoff discharge points on the LRF; water level control and operation of the sluices of the Jardim de Allah (CJA) channel and of the Visconde de Albuquerque channel; fish productivity; survey and registration of fisheries production; dredging operations in the CJA; activation of the organs and agencies involved in the LRF management; monitoring and support in specific actions for the environmental protection of the LRF
Municipal Secretary for the Environment (SMAC)	Municipality of RJ	Monitoring and assessment of water quality of the LRF, and related rivers, channels, and canals of its watershed; assessment of protection monitoring parameters of the biota and aquatic communities; issuing of daily and weekly bulletins with information about the conditions of LRF; activation of the organs and agencies involved in the LRF management; monitoring and support in specific actions for the environmental protection of the LRF
State Institute of the Environment (INEA)	State of RJ	Monitoring of balneability of the local beaches such as Ipanema and Leblon; environmental permitting of activities and enterprises
State Water and Sewage Company (CEDAE)	State of RJ	Construction, operation, and monitoring of the public potable water and sewer systems, including the system of culverts
COMLURB (Municipal Urban Solid Waste Company)	Municipality of RJ	Removal of garbage, solid waste, and dead fish of the water mirror of the LRF

**Table 3.**  
*Main attributions of the public agencies which are involved in the environmental governance and management of the LRF.*

waters is underlined by IBAMA [21, 22]. For this reason, the Cooperative Agreement between the State of Rio de Janeiro and the Town Council of the municipality of the city was celebrated in 2007. The purpose of this was to delegate to the Town Council the relative skills needed by the water bodies located within the municipality, as in the case of the Rodrigo de Freitas Lagoon and the rivers linked to it [23].

The current management of the system of the Rodrigo de Freitas Lagoon is the responsibility of the RIOAGUAS Foundation, in collaboration and partnership with other bodies. The monitoring of the quality of the water of the Lagoon and the affluent rivers and canals is undertaken by the Municipal Secretary for the Environment (SMAC), by means of the Coordinated Body of Environmental Monitoring (CMA) which, in 2011, revived and improved the program previously run by the State Institute of the Environment of Rio de Janeiro (INEA). The RIOAGUAS Foundation carries out daily inspections to detect signs of the *Nessler* effluent reagents, to manage the floodgates, and collect information about fishing and the water level, as well as the silting of the Jardim de Allah Canal through dredging operations.

On the basis of the results of this monitoring, it can be claimed that, in general terms, there has been a noticeable improvement in the environmental standards of the LRF, insofar as its water level has risen. However, the maintenance of the water level of the Lagoon has a direct influence on the flow of rainwater from the districts in the southern zone which are within its surroundings. Hence, there is always a

concern to maintain its level at around 0.40 m, as a preventive measure to reduce the risk of flooding (since events of this kind have been growing in intensity and frequency) which can cause serious damage and immense suffering to the public.

According to Ricci and Medeiros [24], the implementation of policies involving water resources in the basin of the Rodrigo de Freitas Lagoon is still in its early stages. This is because it requires an active attempt to design tools linked to planning, as well as to encourage the strengthening of bodies attached to the Management System of Water Resources. This particularly applies to the planning of activities and the gradual integration of the bodies that already play a role in this area. Ricci and Medeiros [24] argue that the structure created through the cooperative agreement between the State and municipality for the management of the hydrographic basin of the Rodrigo de Freitas Lagoon has become a proof of the considerable importance attached to the management of water resources, since it includes, as an essential prerequisite, the presence of the municipal authorities in the area of management and requires the structuring of municipal power from a techno-administrative, financial, and political standpoint.

These authors recommend that municipal power should be exercised in three fronts to ensure the underlying assumptions about the necessary policies for water resources are made effective: (1) a strengthening of the Management System of Water Resources, in particular, the Committee for the Integration of the Hydric Basin and the Advisory Board; (2) an effective and integrated application of the management tools for water resources; (3) the integration of policies for water resources and other strategic sectors of municipal planning such as sanitation and housing.

It is worth underlining that as a result of the recognized importance of the Lagoon among the people of Rio and the fact that it was a site for Olympic Games competitions in 2016, the LRF has ended up becoming one of the most closely inspected and monitored water bodies in the country.

### **3. Environmental monitoring and the quality of the water of LRF**

#### **3.1 General considerations**

It is not only owing to its environmental importance but also because of its economic, social, and touristic value that the quality of the waters of the Rodrigo de Freitas Lagoon is the object of constant research projects that seek its improvement.

The basic aim of the program called the “Assessment of the Quality of Water in the Rodrigo de Freitas Lagoon and the Rivers and Canals” attached to it is to examine the environmental management of the system formed by its water bodies. Its scope covers the obtaining of environmental information in real time, combined with services for the collection of samples and physicochemical and biological analyses to form a database that can allow an investigation to be carried out of the quality of the water of the Lagoon in the face of natural and anthropic interferences.

Bulletins are issued on the “Quality of the Water in the Lagoon” on a daily basis, and these provide information about the condition of the water with regard to protecting the aquatic communities and making a secondary contact classification (i.e., “appropriate” or “inappropriate”); these are then published in the bulletins from the Center of Operations of the City Council (COR) and also in the Portal of the Council. In the case of the classification of secondary contacts, a limit for the density of 2000 NMP/100 ml of *Escherichia coli* was established for at least 80% of the six samples collected for each of the three areas established in the Municipal Decree 18.415/2000, in accordance with the methodology employed by CONAMA 357/2005.

As well as the bulletins, flags are hoisted on masts that are located in the Parques dos Patins e Pedalinhos (parks for roller skates and paddle boats). Information is provided on the conditions related to the protection of aquatic communities: green flag (balanced state), conditions suitable for an aquatic life; yellow flag (state of alert), conditions of imbalance, which if aggravated, can adversely affect the survival of the aquatic community; and red flag (critical state), unsuitable conditions for aquatic life which can lead to the mass death of the fish.

The control of the quality of the water in the LRF has been carried out by TECMA since 2011, through a contract for undertaking services that include data collection, analyses, making results available, and drawing up periodical reports for the clients (SMAC).

### 3.2 Monitoring carried out by TECMA

The main purpose of the current monitoring which depends on specific and continuous collections is to follow the physical, chemical, and biological alterations resulting from anthropic activities. It also examines the natural phenomena which can impair the quality of the water both for the protection of aquatic communities and for sporting activities in secondary contact and thus recommends what necessary measures should be taken to maintain the quality of the water of the hydric body [11].

The Lagoon requires constant monitoring since it is a naturally vulnerable system that is subject to natural phenomena like stagnation and the deterioration of the quality of the water, the emission of gases, silting, and the high mortality rate of fish [9]. These kinds of problems can be aggravated further by intense urbanization and the discharging of effluents into its waters.

#### 3.2.1 Sampling stations and the monitoring parameters

The specific monitoring of the Lagoon is carried out in six sampling stations, codified from LRF1 to LRF6, with collections being made twice a week by means of portable field equipment and then sent to the laboratory for analysis. This monitoring allows the assessment of the hydric body to be made in sectors that take account of the local dynamics, while the continuous monitoring is carried out by a multiparametric probe located in the center of the Lagoon (LRF3). This allows variations in the quality of the water to be followed in real time and thus rapid action to be taken in the event of situations of imbalance (**Figures 2 and 3**). Every 30 seconds, the probe transmits the measurements to a database made available for the SMAC.

The distribution of the collection stations of the Rodrigo de Freitas Lagoon are designed to gather samples of the three sectors established by the Municipal Decree 18.415/2000, in a representative way. Area 1 depends on four sampling points: LRF1, LRF2, LRF3, and LRF5, according to **Figure 4**. Area 2 has point LRF4, and area 3 has point LRF6. All the points were georeferenced by using the UTM coordinates and are shown in **Table 4**.

In addition to the water of the Lagoon, the water from the rivers of Macacos and Cabeça was also assessed, together with the canals of General Garzon, the Jockey Club (the stretch of the Visconde de Albuquerque Canal which passes by the Jockey Club of the Lagoon), and the Jardim de Alah. One meteorological station, installed at the Rowing Stadium of the Lagoon is responsible for continuously monitoring the climatic conditions of the local region and sending the information to a database every 15 minutes.

Some parameters are monitored in the LRF in both a precise and continuous way, such as is the case with dissolved oxygen, turbidity, salinity, and pH.





**Figure 2.**  
*Portable equipment involved in the precise monitoring.*



**Figure 3.**  
*Buoy containing the multiparametric probe multiparamétrica. (Source: Photos supplied by the TECMA, 2016).*

The specific monitoring still depends on measurements of ammonia nitrogen, total phosphorus, orthophosphate, nitrate, silica, total coliforms, *Escherichia coli*, and the phytoplankton community. There is still continuous monitoring of the chlorophyll parameter a.

In times of drought, technicians from the RIOAGUAS Foundation carried out daily inspections at the points of the rainwater drains where wastewater was directly discharged into the Lagoon or the Jardim de Alah Canal, for the detection of *Nessler* effluent reagents (through a qualitative test for the presence of ammonia which is indicative of recent drainage). However, it was found that, owing to the



**Figure 4.**  
 Location of the collection stations of the Rodrigo de Freitas Lagoon [8].

Collection stations	Location (UTM coordinates)	
	X	Y
LRF1	683289	7459128
LRF2	683910	7459151
LRF3	683250	7458571
LRF4	684117	7458011
LRF5	683023	7457937
LRF6	683898	7457684

**Table 4.**  
 Coordinates for the collection stations of the Rodrigo de Freitas Lagoon [8].

delay in the renewal of the contract between the RIOAGUAS and the company that rendered the operational service for operating the floodgates of the canals linked to the LRF, there was a suspension of the activities required for managing these devices. Added to this, there was an interruption of the desludging, as well as the inspections and conveying of information about the water features and fishing, in the period from November 26 to December 3, 2018.

### 3.2.2 Monitoring data assessment

On the basis of an assessment of the history of the monitoring and through a comparison of the points that were analyzed, it was found that even after the interventions carried out by the policymakers, with the aim of eradicating the effects of effluents, some areas of the Lagoon still had unsuitable environmental conditions with parameters of a quality below what was recommended, as is shown in **Table 5** which refers to data obtained from six monitoring points.

	pH	Temperature (°C)	Salinity of	OD (mg/L)	Turbidity (NTU)	Secchi Disc (cm)	<i>E. coli</i> (NMP/100 mL)	Nitrogen ammonia (mg/L)	Total phosphorus (mg/L)	Total phosphate (mg/L)
<b>Averages of the results for the parameters at the monitoring points—Spring 2014 (Period 22/09 to 20/12)</b>										
LRF1	8.0	27.7	15.3	6.7	2.8	108.3	63	0.234	0.050	0.016
LRF2	8.0	27.7	15.4	6.9	2.6	107.6	70	0.183	0.046	0.016
LRF3	7.8	27.6	15.4	6.2	2.3	119.8	235	0.192	0.047	0.016
LRF4	7.9	27.4	15.4	6.2	2.0	124.3	71	0.185	0.042	0.016
LRF5	7.9	27.6	15.4	6.0	1.7	163.9	396	0.217	0.044	0.016
LRF6	7.9	27.4	15.5	6.1	1.8	134.8	144	0.211	0.040	0.016
Averages	7.9	27.6	15.4	6.4	2.2	126.5	163	0.203	0.045	0.016
Standard Deviation	0.1	0.1	0.1	0.4	0.4	21.0	132	0.020	0.004	0.000
<b>Averages of the results for the parameters at the monitoring points—Spring 2015 (Period 22/09 to 21/12)</b>										
LRF1	8.1	27.6	14.2	6.9	7.7	93.9	642	0.192	0.016	0.016
LRF2	8.2	27.8	14.3	7.1	7.8	93.1	1136	0.147	0.016	0.016
LRF3	8.1	27.6	14.4	6.8	6.9	99.3	835	0.157	0.016	0.016
LRF4	8.2	27.7	14.5	6.8	6.5	102.2	670	0.150	0.016	0.016
LRF5	8.2	27.8	14.5	7.2	7.0	95.0	2916	0.144	0.016	0.016
LRF6	8.1	27.6	14.5	6.7	6.2	102.3	874	0.139	0.016	0.016
Averages	8.1	27.7	14.4	6.9	7.0	97.6	1179	0.155	0.016	0.016
Standard Deviation	0.1	0.1	0.1	0.2	0.6	4.2	869	0.019	0.000	0.000

	pH	Temperature (°C)	Salinity of	OD (mg/L)	Turbidity (NTU)	Secchi Disc (cm)	<i>E. coli</i> (NMP/100 mL)	Nitrogen ammonia (mg/L)	Total phosphorus (mg/L)	Total phosphate (mg/L)
<b>Averages of the results for the parameters at the monitoring points—Spring 2016 (Period 22/09 to 21/12)</b>										
LRF1	8.3	26.6	16.5	7.4	5.7	125.8	61	0.170	0.033	0.016
LRF2	8.4	26.6	16.6	7.1	5.5	130.3	398	0.161	0.037	0.016
LRF3	8.4	26.6	16.6	7.1	4.9	127.5	38	0.160	0.040	0.016
LRF4	8.3	26.6	16.6	7.0	5.2	122.2	78	0.151	0.036	0.016
LRF5	8.3	26.7	16.6	6.9	5.3	115.0	180	0.181	0.034	0.016
LRF6	8.3	26.6	16.6	6.9	5.2	113.6	255	0.172	0.037	0.016
Averages	8.3	26.6	16.6	7.0	5.3	122.4	168	0.166	0.036	0.016
Standard Deviation	0.0	0.1	0.0	0.2	0.3	6.8	139	0.010	0.002	0.000

**Table 5.**

*Comparison of the parameters analyzed in the spring season of 2014, 2015, and 2016 [25] (Note: change all the fractions, e.g., 0.1 > 0.1).*



On the basis of the results for monitoring, an attempt was made to identify the cause(s) and origin of the failure to comply with standards detected in the quality of the water and grounded on the occurrence of parameters that were outside the fixed standards and above the limits recommended. In light of this, analyses of the contributing basins adjoining the nearest discharge points were also taken into account and assessed.

On the basis of its history and previous experiences, as well as the analysis of the points that were being monitored by TECMA, it can be inferred that the values found above the limits can be, without question, related to the illegal links to the sewage and drainage system that discharged waste into the LRF. These links can in turn be attributed to the existence of some remaining vestiges of the informal occupation with regard to the respective drainage basins (and sanitary sewage overflow) in question. In areas of this nonformal typology, the local community lacked suitable sanitation (i.e., an appropriate coordinated system for collecting and/or disposal of the sanitary drainage of the buildings). As infiltration in the soil is not a feasible alternative, what tends to occur is that the effluent waste is discharged in any drainage system that is available.

#### 4. Methodology

The first stage of the methodology employed was to conduct a survey of the bibliographical references, including those regarding the selection of the parameters adopted for this analysis. Several more specific data were investigated that are related to the local drainage basin and the sanitary sewage system, together with an analysis of the locality. The plants and records available of the drainage and sewage systems were investigated together with the respective basins concerned.

These were investigated together with the responsible bodies, including the municipal government of Rio de Janeiro and CEDAE (The State Water and Sewage Company) and the historical data obtained through the monitoring of the quality of the water carried out by the TECMA in the last few years.

There was also an analysis of the field measurement data and the specific collections of the samples taken from the surface water of the Lagoon. This took place twice a week during the period from January 1 to December 31, 2018, in the six sampling points that were strategically placed around the water body (LRF1 to LRF6). These data were made available by the TECMA, and a third party was responsible for analyzing the samples of water from the Lagoon.

Despite the wide array of parameters that were analyzed in the course of the monitoring plan, in the particular case of this study, the physicochemical parameters that were examined were as follows: temperature, salinity, pH, turbidity, dissolved oxygen, ammonia nitrogen, total phosphorus, and orthophosphate. The biological parameters included *Escherichia coli*. The selection of these parameters was based on their degree of importance in representing the hydric quality for required use and grounded on the bibliographical support provided by this study. It should be noted that the parameters for monitoring were the same as those employed by Mello [17].

The temperature, salinity, pH, turbidity, and concentration of dissolved oxygen were determined in situ by means of the portable field recording equipment with electrodes. The samples of water for the analysis of the other parameters were obtained with the aid of collecting bottles and packaged in polyethylene flasks of appropriate volumes. These were duly labeled and preserved and then packed in thermal boxes with ice and sent to the TECMA laboratory for analysis in a timescale that ensured the tests were carried out within the deadline for preserving validity.

It was found that the different groups of phytoplankton displayed variations in their levels of chlorophyll a; since not all the blooming of the algae affected the values of the parameter, they were not regarded as important for the purposes of this study. The benchmark determination methodology in situ, for the collection and preservation of the samples, as well as the analysis, was that recognized by the Standard *Methods for the Examination of Water and Wastewater*, APHA-AWWA-WEF, 22th Edition, 2012.

The results for each parameter were analyzed per season and formulated into line graphs that contain the maximum, minimum, and average values at each stage of the sampling. Calculations were also made of the average values for the surface of each parameter in the years 2014, 2015, and 2016, with a view to supplying comparative values for the seasonal averages of 2018 and thus assisting our understanding of the alterations that were observed. The spatial and temporal variations that were noted were discussed together with the other results. The data were also assessed by comparing them with meteorological data on rainfall, radiation, and air temperature, which was collected from the meteorological station installed in the Rowing Stadium of the Lagoon and also supplied by TECMA, with the aim of determining their influence on the results of the physicochemical and biological parameters.

## 5. Results and discussion

### 5.1 Temperature

Temperature is a factor of paramount importance for the aquatic ecosystem because it plays an essential role in the control of the environment by influencing physical, chemical, and biological processes including vital factors such as primary productivity and the decomposition of organic matter [25, 26]. The Central Institution of the Environmental System of São Paulo (CETESB) [27] stresses the importance of analyzing the temperature of the water, since aquatic organisms have differentiated limits of thermal tolerance and the best temperatures for growth. Thus as high solar radiation naturally results in an increase in the temperature of the water, the supply of water used in refrigeration systems results in a rise in the receptor body which can lead to a reduction in the concentration of dissolved oxygen and/or an acceleration of the metabolism of the phytoplankton which is favorable for the occurrence of blooming. Alterations in temperature can also sharpen the sensation of taste and smell in the water [28].

In the period being analyzed, it was noted that there was a horizontal uniformity in terms of water temperature on the surface layer of the Rodrigo de Freitas Lagoon. The averages, with regard to the six sampling points, ranged from 24.1 to 30.0°C, with lower temperatures in winter and higher in summer (**Figure 5**).

#### 5.1.1 Temperature and phytoplanktonic blooming

It was noted that together with other factors, the high temperatures of the water in the Lagoon in the spring of 2018 could have favored the phytoplanktonic blooming of the cyanobacteria *Synechocystis* spp., which occurred in the period December 10–17. It should be underlined that the fact that cyanobacteria have a preference for high temperatures has been demonstrated in a number of studies [29–31].

When compared with the springs of 2014, 2015, and 2016, the parameter in 2018 was 1–1.5°C above the others as can be observed in **Table 6**.

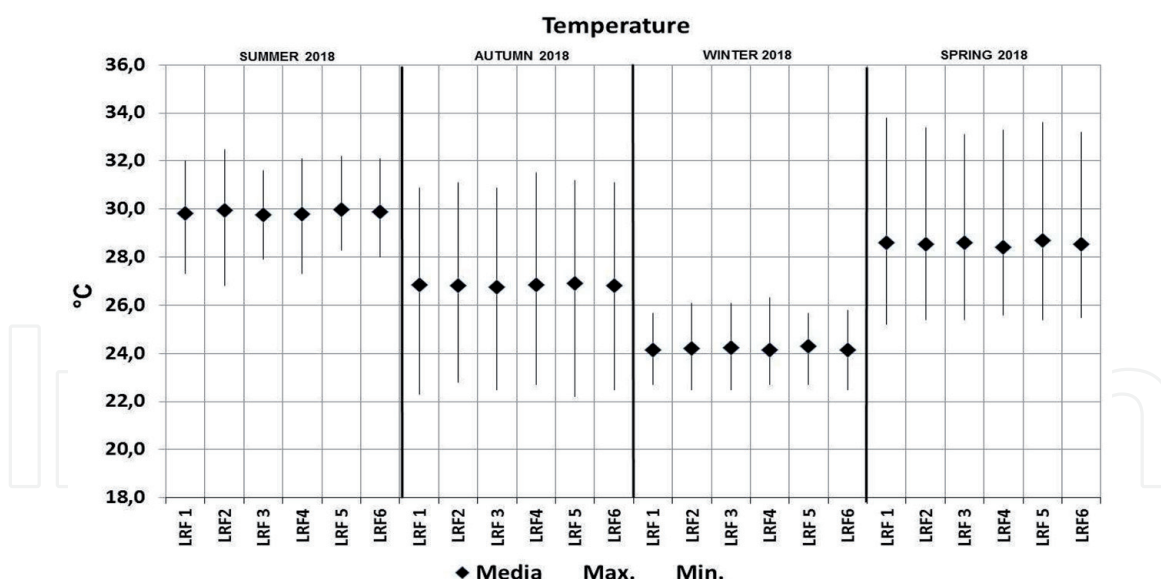


Figure 5. Temperature of the surface of the LRF in 2018.

## 5.2 Salinity

Water temperature (°C)				
Averages at sampling points	2014	2015	2016	2018
	27.6	27.7	26.6	28.2

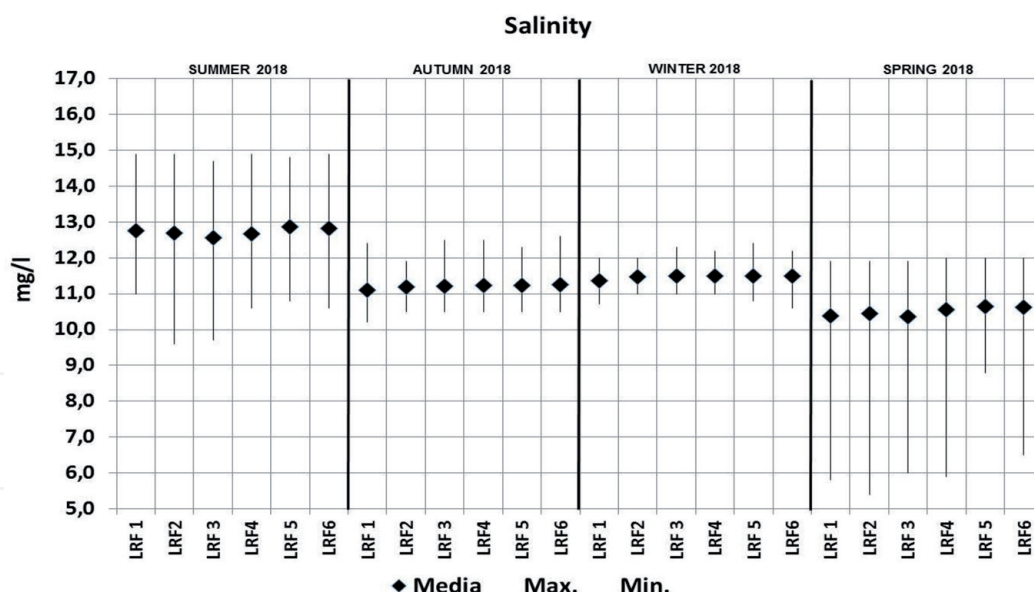
Table 6. Average water temperature at the LRF during the monitored spring seasons.

Salinity is another factor that influences the biodiversity of hydric bodies, since different species have different ways of adapting to concentrations of mineral salts [28]. They are reduced to colonies of brackish environments by aquatic animals and superior vegetation, owing to the difficulties of osmoregulation which, according to Reid and Esteves [32], constitute one of the main factors responsible for the low phytoplanktonic diversity of the coastal lagoons of the State of Rio de Janeiro.

In the same way as temperature, salinity can have a great influence on the stratification of the water bodies, since the density of the water increases when there is a rise in the concentration of salts [28]. Esteves [33] underlines the fact that when there is a rise in temperature, an increase in salinity reduces the capacity of the water for the dissolution of oxygen.

The values for salinity that were observed for spring 2018 were relatively low, and this can probably be attributed to the pluvial and fluvial effects of the waters and to a less extent, to the sea and evaporation (Figure 6). It was found that the three greatest falls in salinity occurred in the periods November 8, 19, and 26 and coincided with the heavy rainfall recorded on those days. Attention should also be drawn to the fact that there was a lack of an entry for water from the sea owing to the low tide, a failure in the operation of the floodgates, and the constant silting of the Jardim de Alah Canal.

This silting was also recorded by Kaippert [16] and Lima [5] as a factor that involved a marine influence on the LRF. It is also worth noting that the values



**Figure 6.**  
 Salinity of the surface of LRF in 2018.

Salinity				
Averages at sampling points	2014	2015	2016	2018
	15.4	14.4	16.6	10.4

**Table 7.**  
 Average water salinity at the LRF during the monitored spring seasons.

recorded on the days in question in November 2018 were the lowest since the monitoring by TECMA first started in 2011 and that the parameter that can influence the establishment of organisms includes the phytoplankton community.

### 5.2.1 Salinity and phytoplanktonic blooming

In the spring of 2018, there were records of phytoplanktonic blooming of the cyanobacteria *Synechocystis* spp., in the period December 10–17. Domingos et al. [1] argue that a rise in salinity is a limiting factor for the presence of cyanobacteria of the *Synechocystis* genus. This means that the reduction of the values of the parameter may have provided conditions that were favorable to their growth in the Lagoon.

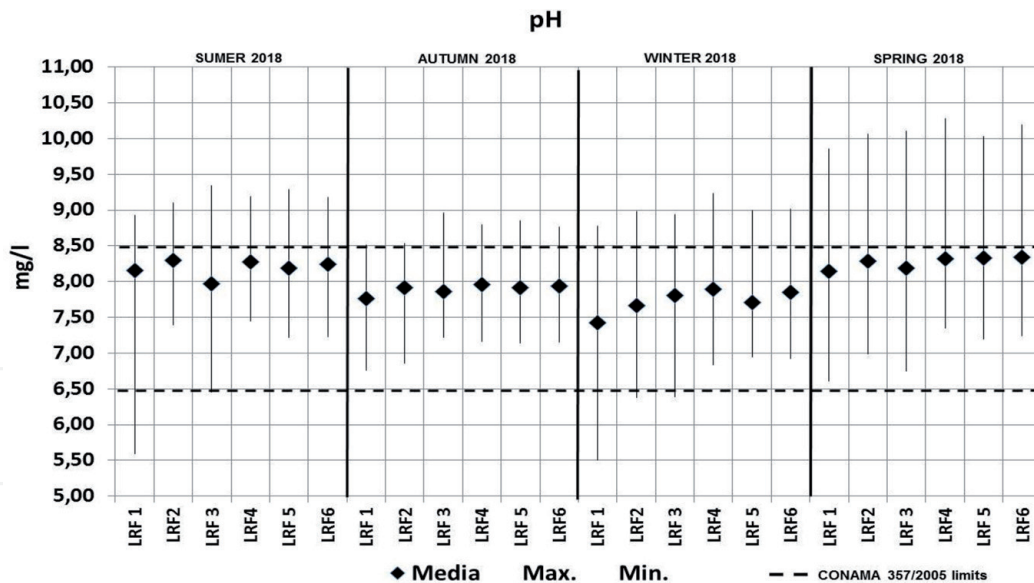
When compared with the springs of 2014, 2015, and 2016, the parameter was between 4 and 6 units below the others in 2018 as induced in **Table 7**.

### 5.3 pH

Another key parameter for the monitoring of hydric bodies is the pH, because not only it influences the solubilization and sedimentation of metals and other substances, but also it acts in different ways on the metabolism of aquatic communities by making a direct intervention in the distribution of the organisms [33, 34]. The pH must be situated in values of 6.0–9.0 for the maintenance of aquatic life, since values outside this range are usually harmful to most aquatic creatures [35, 36].

The values of pH are caused by natural phenomena such as the dissolution of rocks, the absorption of atmospheric gases, oxidation of organic matter and photosynthesis, as well as anthropic factors like the discharge of domestic effluent





**Figure 7.**  
*pH of the surface of LRF in 2018.*

(oxidation of organic matter) and industrial waste, which underlines the importance of this parameter in the assessment of human interference in the quality of water [35]. In the case of the lagoons which undergo influence from the sea, the salt water can bring about large quantities of carbonate and bicarbonate ion by causing a rise in pH, in the same way that an increase in rainfall can lead to a reduction of the values. In environments where there is a high phytoplanktonic density, the pH can naturally reach values above 9.0 during the period of maximum sunlight, owing to the photosynthetic activity of the algae which consume the CO<sub>2</sub> [37].

The average surface values of the pH range from 7.42 to 8.35, with maximum values being recorded in the spring (**Figure 7**). It was noted that during the year of 2018, all the maximum surface values of pH surpassed the maximum limit of the 6.5–8.5 bands that was established by law for brackish waters of class 2.

### 5.3.1 pH and the phytoplanktonic blooming

When compared with the springs of 2014, 2015, and 2016, the parameter in 2018 was slightly above the others, which as pointed out by CETESB [27] might be linked to greater photosynthetic activity caused by a higher intake of CO<sub>2</sub> as induced in **Table 8**.

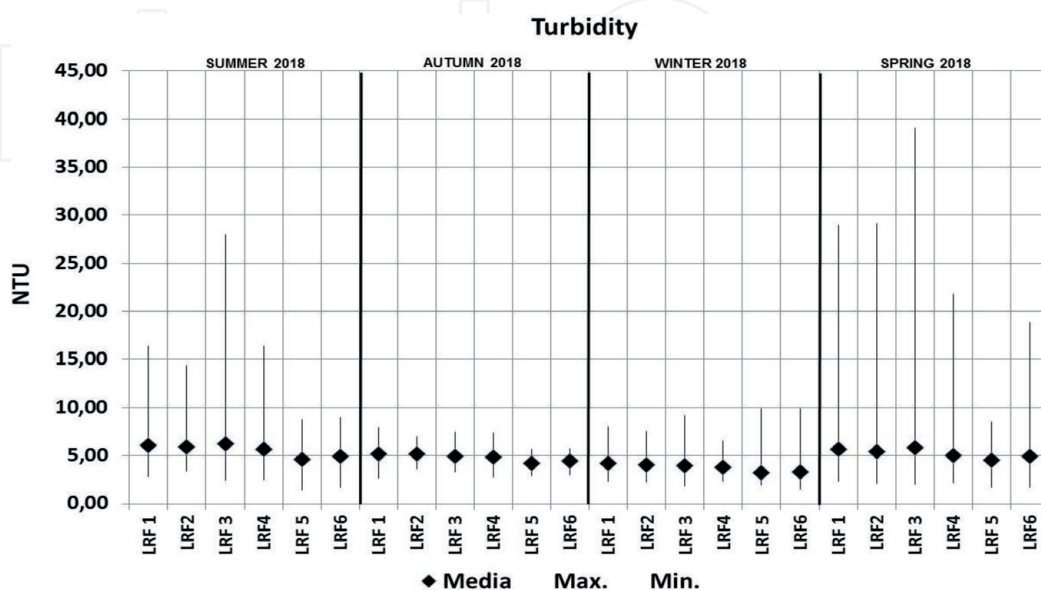
It is noteworthy that in the spring of 2018, there was a blooming of the cyanobacteria *Synechocystis* spp.

## 5.4 Turbidity

Alterations in the penetration of light are described as turbidity, and this can be caused by particles in suspension such as bacteria, phytoplankton clays, silting, organic and inorganic detritus, and dissolved compounds [25, 33]. Apart from a rise in the turbidity of the waters caused by a discharge of effluent, a natural phenomenon that also causes this rise is the erosion of the shores of the water bodies in periods of heavy rainfall. Since a high level of turbidity hinders the penetration of the solar rays in the water, this is able to reduce the photosynthesis of the plants and submerged algae and, as a result, influence the dynamics of the local biological community. In addition, it has an adverse effect on the domestic, industrial, and recreational use of the water in question [26].

pH				
Averages at sampling points	2014	2015	2016	2018
	7.9	8.1	8.3	8.4

**Table 8.**  
 Average water pH at the LRF during the monitored spring seasons.



**Figure 8.**  
 Turbidity of the surface of the LRF in 2018.

The Lagoon showed low levels of turbidity for most of the year although some peaks were observed, particularly in the summer and spring which are the months with most rainfall. The averages in the seasons when the sampling was carried out range from 3.2 to 6.2 NTU (Figure 8).

It was found that in the collection of November 26, there was a sharp rise in all the points of the parameter that is represented by the maximum values observed in spring. These results reflected the heavy rains recorded on that day, when the second highest accumulation of rainfall in the year was recorded in a period of 24 h (102.60 mm). Rosman [4] points out that since it is the lowest point of the hydrographic basin, the LRF has enormous inflows of dissolved substances carried along by the force of the downpours of rain. It should be noted that although the legislation (CONAMA 357/2005) does not determine the maximum value for the parameter, in the case of brackish waters, it recognizes that there are virtually no signs of substances that produce turbidity.

However, when compared with the springs of 2014, 2015, and 2016 in Table 9, the spring of 2018 did not stand out with regard to the turbidity parameter. It is noteworthy that the spring of 2014 was the driest among all the monitored spring seasons.

### 5.5 *Escherichia coli*

The role of the microorganisms in the aquatic environment is essentially confined to transforming matter within the cycle of various elements with a view to obtaining energy for survival. The decomposition of organic matter into simpler substances, which is largely carried out by putrefactive bacteria, is one example of these changes. This is because it is vital for the aquatic environment, given the

Turbidity (NTU)				
Averages at sampling points	2014	2015	2016	2018
	2.2	7.0	5.3	5.9

**Table 9.**  
Average water turbidity at the LRF during the monitored spring seasons.

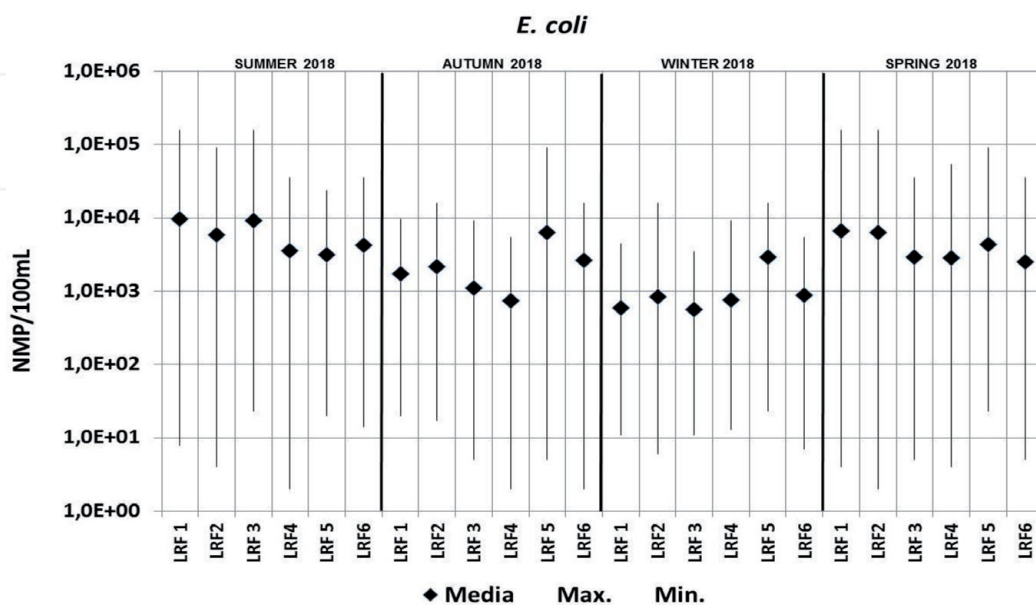
fact that the resulting nitrates, phosphates, and sulfates are reassimilated by other organisms in the environment [36]. Nonetheless, there are also microorganisms that are potentially an obstacle to the maintenance of the quality of the water body.

For this reason, a biological parameter of crucial importance in monitoring the quality of the water is the number of coliforms, in particular those that are thermotolerant and are present in the sample obtained. Since in most circumstances, the populations of thermotolerant coliforms predominantly consist of *Escherichia coli*, this group is regarded as a suitable indicator of the quality of the water since its presence is a sign of recent fecal contamination [36, 38]. The limit of *E. coli* used by SMAC for the Lagoon is based on the CONAMA Resolution 357/2005, which is 2000 NMP/100 mL.

In 2018, the densities of *Escherichia coli* showed a wide variation, although without any seasonal fluctuation being characterized (Figure 9). However, it should be noted that in winter, the average density was, in general terms, reduced, whereas in summer and spring, (the period with more rainfall), the maximum and average values were higher. It was found that that the results were a great deal higher at the points LRF1 and LRF2.

When compared with the springs of 2014, 2015, and 2016 in Table 10, the parameter for 2018 was between 5 and 30 times higher than the others.

Some of the factors that can influence the colimetrics results in the LRF are as follows: entries of organic matter through surface drainage, the opening of the floodgates, and the entry of the sewer system originating from an excessive number of leaks in the culverts during periods of rainfall [7, 8, 15]. In addition, there are often reports of the discharges of effluent in periods of drought at the rainwater



**Figure 9.**  
*Escherichia coli* in the surface of the LRF in 2018.

<i>Escherichia coli</i> (NMP/100ml)				
Averages at sampling points	2014	2015	2016	2018
		163	1.179	168

**Table 10.**  
 Average *Escherichia coli* at the LRF during the monitored spring seasons.

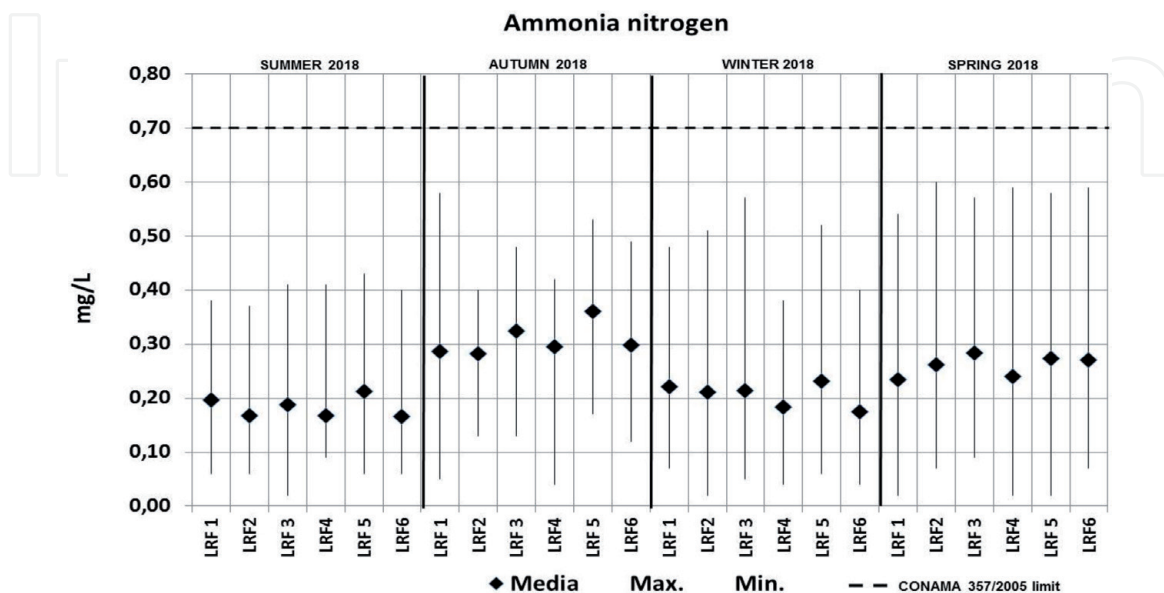
outlets arranged around the Lagoon, as already mentioned [16, 17]. The presence of ammonia in the water can be detected through the reaction of the *Nessler* reagent to a qualitative test for the presence of ammonia, which is an indicator of recent drainage.

### 5.6 Ammonia nitrogen

Ammonia nitrogen is formed by ammonia species ( $\text{NH}_3$ ) and ion ammonia ( $\text{NH}_4^+$ ), which is the most toxic species in the aquatic organisms [39]. The CONAMA Resolution 357/2005 stipulates 0.70 mg/L N as the limit of total ammonia nitrogen for the brackish waters of class 2, regardless of the pH [40]. Nitrogen is regarded as one of the most important elements in the metabolism of aquatic ecosystems for directly protecting aquatic life. This is also due to its role in the formation of proteins and chlorophyll [33].

The values of ammonia nitrogen showed a wide variation in 2018, although the seasonal fluctuations were not defined (**Figure 10**). However, it should be pointed out that, generally speaking, in summer the averages were reduced, while spring showed the highest maximum values, with the detection of a considerable increase in the parameter after heavy rainfall, mainly on October 15 and November 26. This rise in ammonia nitrogen can be attributed to the entry of organic matter and other substances into the Lagoon.

The inorganic forms of nitrogen, mainly ammonia nitrogen and nitrate, are ideally assimilated by phytoplankton [41–43]. During the period of phytoplanktonic blooming which took place between December 10 and 17, 2018, there was a reduction in the values of ammonia nitrogen, with a subsequent rise of the parameter at the end of the blooming period.



**Figure 10.**  
 Ammonia nitrogen on the surface of the LRF in 2018.



Ammonia nitrogen (mg/L)				
Averages at sampling points	2014	2015	2016	2018
	0.203	0.155	0.166	0.274

**Table 11.**

*Average Ammonia nitrogen at the LRF during the monitored spring seasons.*

When compared with the springs of 2014, 2015, and 2016 in **Table 11**, the parameter in 2018 was between 0.071 mg/L and 0.119 mg/L above the others.

CETESB [26] establishes that the control of eutrophication by reducing the intake of nitrogen was adversely affected by the numerous sources, some of which are hard to control like the fixation of atmospheric nitrogen on the part of the algae. In this way, an investment was made in controlling the sources of phosphorus.

## 5.7 Dissolved oxygen

Dissolved oxygen (DO) is the main element in the metabolism of aerobic aquatic organisms such as fish and planktonic microorganisms. It is because of its importance in the maintenance of aquatic life that the DO is used as the main parameter for the quality of the water. CONAMA 357/2005 stipulates a minimum value of 4.00 mg/L of DO for class 2 brackish water.

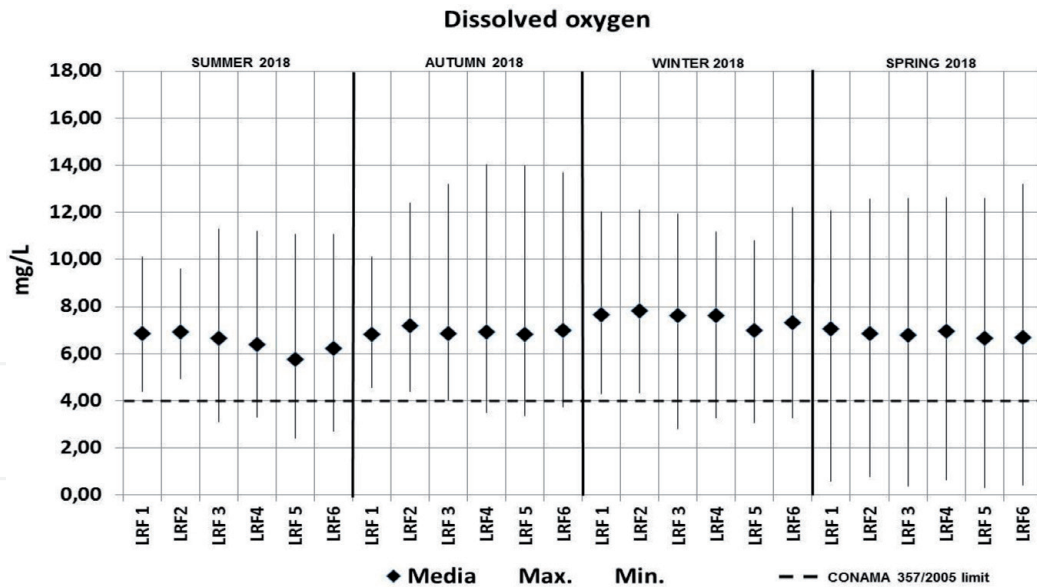
The principal sources of oxygen for the aquatic ecosystem are the atmosphere and the photosynthesis of the algae, while its consumption is related to the decomposition of organic matter, the respiration of aquatic organisms the oxidation of ions, and losses to the atmosphere [39]. Low concentrations of dissolved oxygen in the water can cause delayed growth, a reduction in efficient feeding practices, and an increase in the incidence of diseases and the mortality of fish [44].

Polluted water tends to have low concentrations of dissolved oxygen owing to its consumption in the oxidation of the organic compounds, whereas clean water displays higher concentrations of DO [34]. However, systems with eutrophication can have supersaturated conditions, with concentrations of oxygen higher than 10 mg/L, even in temperatures above 20°C. According to CETESB [26], this mainly occurs in lakes with low speeds where algae soil crusts are formed on the surface.

### 5.7.1 Dissolved oxygen during blooming and fish mortality

During the year that was analyzed (2018), there was a wide variation in the concentrations of DO on the surface of the Lagoon (**Figure 11**). Esteves [33] points out that the rise in temperature and salinity reduces the capacity of the oxygen to dissolve in water. For this reason, summer (the season which showed the highest values in these parameters) recorded the lowest average concentrations of DO. However, it should be noted that the lowest minimum concentrations of DO occurred in spring, after the senescence. Then there was a sharp reduction and consequent aerobic decomposition of the phytoplanktonic population of *Synechocystis* spp., which was in bloom, leading to records of the mortality of fish by anoxia in the LRF, from December 20 to 23, 2018.

Esteves [33] states that owing to high temperatures, the decomposition of organic matter in tropical waters occurs 4–10 times more rapidly than in temperate climates, which involve a proportionally greater intake of oxygen. In the case of shallow water bodies, like the case of LRF, the concentration of organic matter combined with high temperatures is a decisive factor in determining the degree of deoxygenation.



**Figure 11.**  
 Dissolved oxygen in the surface of the LRF in 2018.

When compared with the springs of 2014, 2015, and 2016 in **Table 12**, the parameter in 2018 was between 0.6 and 1.2 mg/L above the others.

The amount of oxygen can either increase through the intensification of photosynthetic production or decline if there is greater respiration among the local communities and/or a greater oxidation of organic matter. Temperature has a direct influence on both the respiration of the organisms and the other oxidative processes like the decomposition of organic matter by aerobic microorganisms and hence has an effect on the levels of dissolved oxygen.

### 5.8 Total phosphorus and orthophosphate

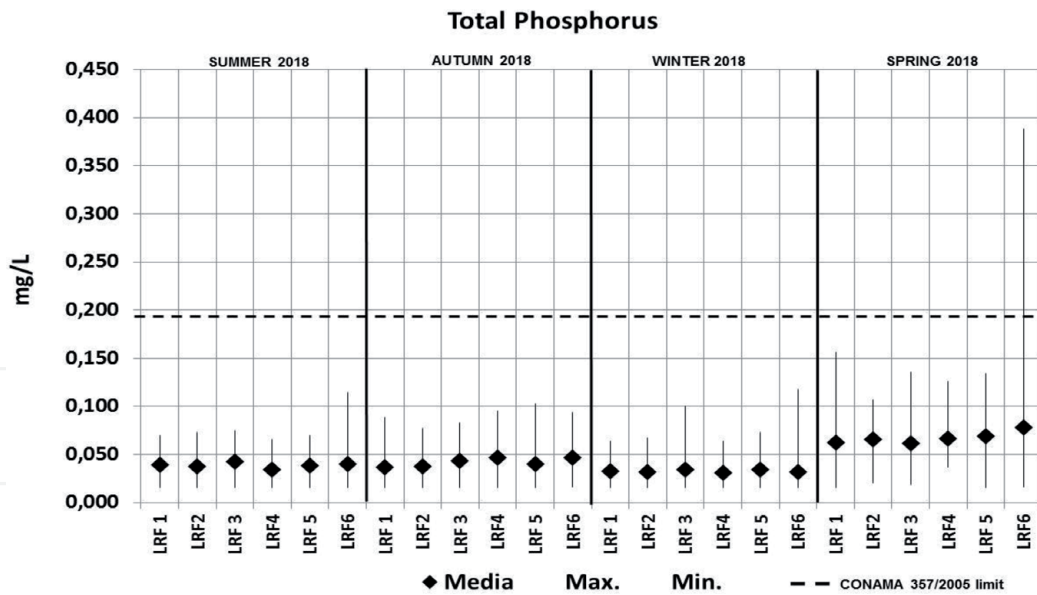
Organic matter is rich in nutrients like nitrogen and phosphorus which, in excess, can cause an imbalance with regard to the production and consumption of biomass, a condition known as eutrophication [45]. According to Esteves [33], phosphate is cited as being responsible for the artificial eutrophication of continental waters, the most important artificial sources being the sewage systems and the particle material of industrial origin.

Although the legislative regulations of CONAMA (357/2005) define the maximum limit of 0.186 mg/L for total phosphorus and separate phosphate fractions, it is the monitoring of the orthophosphate in water bodies that is most important since it is the main means of assimilating primary end consumers [33].

No significant differences were observed in the average levels of total phosphorus between the different points (**Figure 12**). Although the highest values were found in spring, it was only in point LRF6 that the limit of 0.186 mg/L (that was established by CONAMA Resolution 357/2005) was surpassed for brackish water of class 2. It was

Dissolved oxygen (mg/L)				
Averages at sampling points	2014	2015	2016	2018
	6.4	6.9	7.0	7.6

**Table 12.**  
 Average water DO at the LRF during the monitored spring seasons.



**Figure 12.**  
Total phosphorus in the surface of the LRF in 2018.

noted that this failure in compliance occurred on December 19, or in other words, at the end of the phytoplanktonic bloom that took place in the Lagoon in the spring of 2018.

When compared with the springs of 2014, 2015, and 2016 in **Table 13**, the parameter in 2018 was 0.026–0.055 mg/L above the others.

Similarly, no significant differences in the average levels of the orthophosphate were found between the points (**Figure 13**). A similar behavior for the total phosphorus was noted with higher values in spring.

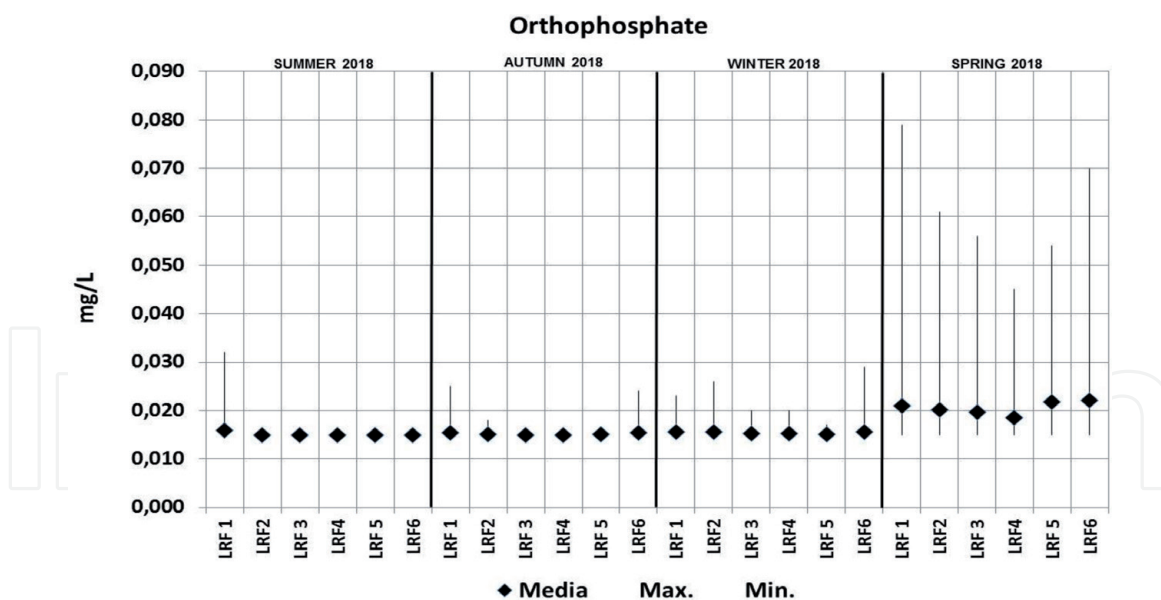
When the springs of 2014, 2015, 2016, and 2018 are compared in **Table 14**, it was only in the last that average values of orthophosphate were recorded above 0.016 mg/L, suggesting there was a rise in the input of nutrients in this particular spring.

The rise in total phosphorus and the more significant orthophosphate was recorded on December 3 and could have resulted in the entry of a large amount of organic matter and other substances into the Lagoon after the rainfall that occurred between November 26 and December 8. The significant rise of the parameters on December 19 might be owing to the decomposition of the phytoplankton, which was in bloom, which means these nutrients were replaced and made available in the environment. In the same way, the higher values recorded in December 26 may have resulted from the decomposition and the return to the environment of the components after the mortality of about 89 tons of fish which took place in the LRF between December 20 and 23, 2018.

It should be noted that Lopes and Magalhães [34] point out that the growth, death, and decomposition of aquatic organisms have a harmful interference on the quality of the water owing to alterations in the levels of nitrogen, phosphorus, pH, and dissolved oxygen.

Total phosphorus (mg/L)				
Averages at sampling points	2014	2015	2016	2018
	0.045	0.016	0.036	0.071

**Table 13.**  
Average total phosphorus at the LRF during the monitored spring seasons.



**Figure 13.**  
 Orthophosphate in the surface of the LRF in 2018.

Orthophosphate (mg/L)				
Averages at sampling points	2014	2015	2016	2018
	0.016	0.016	0.016	0.022

**Table 14.**  
 Average orthophosphate at the LRF during the monitored spring seasons.

## 6. Conclusion and recommendations for further study

In the analysis that has been conducted which adopted an approach from a seasonal standpoint, it was not evident from the results of the parameters used for monitoring that there was a considerable variation in the results between the different collection points (LRF1 to LRF6). On the other hand, it can be argued that in general (with regard to all the points monitored), the spring of 2018 was the season of the year that had the most significant alterations. When compared with the previous springs (those of 2014, 2015, and 2016), it was also shown to have undergone most alterations in the parameters that were analyzed.

It is worth stressing that the blooming of the algae occurred in December 2018, as the result of the combination of two factors: the availability of nutrients and the suitable conditions with regard to temperature and salinity. High temperatures were found in this period, which favored lower levels of oxygen in the water column, as well as heavy rainfall which led to a large input of nutrients going to the Lagoon.

In addition, there was a period of failure in the floodgate management which affected the entry of water from the sea and hence heightened the problem of the reduction of the values of salinity, which is an important (if limited) parameter for the establishment of *Synechocystis* spp. At the end of the blooming period of these algae, there was a large fish mortality caused by anoxia. In view of this, attention should be paid to the influence of the Rua General Garzon Canal (notorious for its contamination) in the LRF when its floodgates are opened. For this reason, there is a serious need for a suitable management of floodgates that comply with the guidelines of the protocol of the Municipal Contingency Planning of the Rodrigo de



Freitas Lagoon. By analogy, the desludging operations of the Jardim de Alah Canal are of extreme importance. As reported earlier, even gentle breezes can mix with the column of water and favor the horizontal uniformity of the water mass, while specific alterations can influence the Lagoon as a whole.

On the basis of the detailed results, it can be argued that particular places in the Lagoon are more prone to the harmful effects of the illegal dumping of sewage, such as those close to the General Garzon Canal and also the Jardim de Alah Canal. However, in light of seasonal factors, it cannot be stated which points undergo a significantly more serious impact from the release of sewage, and further continuous monitoring is needed together with more detailed analyses to make this determination.

At all events, it is of crucial importance to carry out the monitoring and surveillance activities of the illegal dumping of waste material. This should be undertaken in a systematic and continuous way at the customary outlet points with a view to detecting and eradicating these illegal systems. Tests should be carried out to detect the origin of these clandestine practices in the drainage system and include dyes and tracers in the piping, upstream and downstream, beginning with the places where these practices are occurring. This can be assisted by drawing on the records available of the sewage systems (CEDAE) and drainage networks (RIOAGUAS), as well as information about the respective operational districts that are responsible for the maintenance of these systems. Setting out from a clear idea of the origins of the clandestine and illegal practices, a specific study should be undertaken to adjust these situations of non-compliance. This can entail introducing a project about sanitary sewage disposal which can make the economic infrastructure of the area viable without the need to be interconnected with a completely separate waste disposal system.

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