The Importance of Geochemistry in the Management of Lake Environments: Analysis of Parameters Composing the Water Quality Index (Wqi)*

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Abstract

The present work aims to elaborate a review of the geochemical aspects used to compose the Raw Water Quality Index (WQI), highlighting lake environments and their importance for management practices. This paper is a bibliographic review based on specialized scientific and legislative literature conducted between April 2016 and March 2019. The scientific articles were selected by searching the Scielo database and the Periódicos Capes and the database search was performed using the terminologies registered in the Descriptors (Thesaurus) or Keywords (Scopus and Web of Science) for geosciences and environmental sciences. The WQI is the main quality index used in the country and is calculated based on nine parameters (water temperature, pH, dissolved oxygen, total residue, biochemical oxygen demand, thermotolerant coliforms, total nitrogen, total phosphorus and turbidity). The values determined through the calculation of the WQI are classified in ranges that define the water quality, which varies between different Brazilian states. Among its mishaps, it is noteworthy that the WQI does not analyze other factors important for public supply, such as toxic substances (eg: heavy metals, pesticides, organic compounds), pathogenic protozoa and substances that interfere with the organoleptic properties of water, which are under other management tools. The systemic model of water resources management adopted for Brazil is still in the process of improvement, because it still works through a decentralized system where the public authorities, at different levels, have an active voice, thus requiring the commitment to make a long-term monitoring based on a reliable geochemical analysis, so that an integrated management can be carried out, allowing the synthesis and characterization of the current state and management criteria of lake environments, with the main objective of facing the conservation challenges allied to sustainable use of its resources.

Keywords

WQI, Lakes, managemet, parameters

Subject Areas: **Environmental Sciences,Geochemistry,Hydrology**

1. Introduction

Lakes and lagoons are ecosystems belonging to watersheds of recognized importance in different geological and ecological processes, such as full and ebb attenuation, reduction of surface erosion, water quality conditioning and maintenance of canals by the protection of margins and siltation reduction [1]. There is broad scientific consensus (ABC/SBPC) that these are ecosystems that, for their stability and functionality, need to be conserved or restored if historically degraded.

Degradation of lakes and lagoons in the world is an important topic for Global Aquatic Resources, which arouses and requires attention, since lakes, in addition to their importance as a component of the ecosystem regulation, contains more than 90% of the fresh water available for human consumption in terrestrial surface [2].

Among the main values of the resources offered by the lakes and reservoirs, the most relevant ones can be divided into three main groups: provision services (drinking water supply, irrigation, navigation, fishing and tourism), regulation services (flood and drought, management , drainage, climate remediation) and cultural services (religious and historical values) [3].

With the continually increasing of global population, providing adequate drinking water supplies is becoming a critical challenge. Therefore, there is a crucial importance regarding the attention of different administrative spheres to the protection of lake and reservoir ecosystems, the former being more vulnerable to different environmental impacts.

Currently, Brazil has a solid legal framework for water management, especially the decentralized management that allows the participation of the Public Authority at different levels of action, of users and society in general [4].

At the apex of the institutional framework is the National Water Resources Council and, in the states, the State Water Resources Councils, which discipline procedures and arbitrate conflict situations. At the same time, there are about 150 state and interstate basin committees installed in different regions of the country, which deliberate on water resources plans and required action priorities [5].

This set, which configures the National Water Resources Management System - SINGREH, along with the management instruments defined by law[1], are in full force throughout the country. Thus, the differences regarding the institutionality, the management criteria, and the technical capacity installed in each state are clear, which, to some extent, still require improvement [6].

The wide necessity and scope of geoscientific studies, and especially the geochemical ones, is justified not only for the environmental scientific knowledge, but mainly in the determination of the impacts that the different types of uses, enterprises, projects and actions in the lakes and lagoons can cause when effectively immersed in physical reality [7].

The parameters commonly used to study water quality in lakes and reservoirs are: (physical) sunlight, temperature, turbidity, particulate matter in suspension, conductivity and color; (chemical) dissolved oxygen, salinity, pH, alkalinity, phosphates, nitrates and ammonia, organic carbon, among others; (biotic) phytoplankton, zooplankton, fish, crustaceans, aquatic invertebrates; (hydrological) surface area, discharge or flow, holding time, fluctuation, depth, continuity; (geomorphological) vegetation cover of the basin, urban agglomerations, riparian and riparian forest, landscape evolution [8].

According to the National Water Agency, the main water quality index used in the country is the WQI, created in the United States by the *National Sanitation Foundation* in 1970 and used by CETESB (Environmental Company of the State of São Paulo) since 1975. The WQI is a simple mathematical model that determines water quality based on nine parameters (thermotolerant coliforms, pH, biochemical oxygen demand, nitrate, total phosphate, water temperature, turbidity, total solids and dissolved oxygen), giving a corresponding weight for each according to their importance.

The WQI therefore bases its qualification on water quality based on parameters that bring as aggregate information water contamination due to organic and fecal matter, solids and nutrients, but has limitations when considering that this index does not take into account other parameters indispensable for the qualification of a body of water as suitable for public supply, such as the incidence of toxic substances (e.g. heavy metals, pesticides, organic compounds), occurrence of pathogenic protozoa and other substances that may interfere with organoleptic properties of water.

Nutrients are essential elements for the development of aquatic biota, especially in confined environments that can, in excess, cause the eutrophication of lakes and reservoirs, that is, their exaggerated enrichment, with considerable damage to the environment. The main nutrients are Phosphorus, Nitrogen, Carbon and Silica [8].

[1]They are instruments of the National Water Resources Policy, according to Law no. 9.433 / 97: a) Water Resource Plans; b) the classification of water bodies into classes, according to the predominant uses of water; c) the granting of rights to use water resources; d) charging for the use of water resources; and e) the Water Resources Information System.

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Therefore, this paper aims to elaborate a synthesis and characterization of the current state of management criteria and review of geochemical aspects and environmental indicators evaluated in lake environments used to compose the raw Water Quality Index (WQI).

2. Material and Methods

This paper is a bibliographic review based on specialized scientific and legislative literature conducted between April 2016 and March 2019. The scientific articles were selected by searching the Scielo database and the Periódicos Capes portal using the publication dates (considering the lower limit of 2010) and the impact factor (ratio between the number of times articles of a journal are cited and the total number of articles published each year) as the criteria of their choice in each journal consulted.

The database search was performed using the terminologies registered in the Descriptors (Thesaurus) or Keywords (Scopus and Web of Science) for geosciences and environmental sciences.

The methodology of this research can be divided into two main stages: (i) a stage regarding the thorough search for scientific texts and official legal clauses related to the subject; (ii) another in which the texts found were analyzed regarding their content.

To conclude the analyses, discussion meetings were held with the Interface Geochemistry research group, from the Federal University of Bahia.

3. Results

3.1 Management Criteria

The maximum levels of impurities allowed in water are set according to their uses. These constitute the quality standards that are set in order to ensure that the water to be used does not contain impurities that may harm it or, in the case of effluent discharges, that they will not cause damage to the environment.

It is important to highlight the difference between criteria and standards of water quality. The definition of water quality criteria deals with maximum tolerable values that guarantee the intended uses of water considering generic exposure conditions. The criterion becomes a quality standard when it is cited in legislation, its establishment requires appropriate toxicological studies [3].

Water quality criteria are established individually for each type of use, namely: human consumption, recreation, animal desedentation, irrigation, aquatic life protection and aquaculture.

Water quality standards express desirable physical, chemical and biological characteristics in waters due to their predominant uses. In order to protect water bodies, legal restrictions have been instituted to maintain physical, chemical and biological characteristics within certain limits [9].

Water quality standards and criteria in Brazilian legislation are produced with a view to meeting water uses, such as public supply, bathing, irrigation, fishing, among others. Such uses are protected by the standards set by the following laws: Ministry of Health Ordinance No. 2914/11, CONAMA Resolution No. 274/2000, CONAMA Resolution No. 357/2005 [3].

The occurrence and management of problems in a lake environment are mainly influenced by three specific characteristics of this type of ecosystem: (i) its integrative nature, (ii) long retention time and (iii) a complex response dynamics [10].

The first feature means that problems in these environments are rarely located within lakes. Its origin comes from the environment in which it is located and is eventually introduced as part of ecosystem problems, for example flooding affecting the lake shore; pollution that spreads can affect much of the environment, and biological problems, such as non-native species but eventually introduced, also pose threats. The relatively long retention time means that problems take a long time to become apparent. And the complexity of lake dynamics influences the way problems become evident.

Water quality is the result of processes that occur on the surface of the watershed and is strongly dependent on the natural characteristics of the watershed, such as soil type, vegetation and climate, as well as on anthropic activities [3].

Among the main problems behind the preservation of today's lake basins of biological origin are the overgrowth of aquatic plants, which alter native fauna habitats, interfere with water transport, harbor harmful species, prevent water flows and increases lake surface evapotranspiration [11] and the introduction of wild species that can compete for food resources or become predators of native species [21].

Regarding aspects of chemical origin, there are changes in the salinity of lakes that disrupt some ecosystems, consequently harming the communities dependent on them. Nutrient accumulation is also a factor that influences the various communities promoting the eutrophication of aquatic plants. This problem is particularly common in Asian lakes. Soil erosion and fertilizer use are also responsible for excess diffuse inputs from nutrient sources, which can cause so-called agro-chemical pollution, which affects aquatic food chains and makes fish unfit for human consumption [11].

Human activities such as deforestation, unproductive land use and poor management of riparian forest in lake basins result in excess sediment inputs and reduction of wetlands, not to mention dumping untreated or poorly treated waste, contaminating lakes and reducing concentrations of oxygen and nutrients, which increases the eutrophication of the lake. In addition to these factors, there are predictions that climate change and global warming cause changes in precipitation and runoff, as well as changes in the thermodynamic and ecological balance of lakes [10].

Watershed and water resources problems are very similar around the world. What differs is the perception about the seriousness of the problems and the ability of governments to deal with them. Eutrophication, for example, is seen as a negative aspect in developed countries. However, the increase in aquatic production associated with eutrophication is considered a positive quality in Southeast and South Asia and in other regions where aquaculture is practiced and fish enclosures and farms exist [10].

3.2 Geochemical Parameters

Dissolved oxygen

Among the gases dissolved in water, oxygen (O2) is one of the most important in the dynamics and characterization of aquatic ecosystems. The main sources of oxygen for water are the atmosphere and photosynthesis. On the other hand, the losses are the consumption by decomposition of organic matter (oxidation), losses to the atmosphere, respiration of aquatic organisms and oxidation of metallic ions such as iron and manganese [12].

Dissolved Oxygen is indispensable to aerobic organisms; waters with low dissolved oxygen levels indicate that they have received organic matter; decomposition of organic matter by aerobic bacteria is usually accompanied by consumption and reduction of dissolved oxygen in water; depending on the self-purification capacity of the lake, the dissolved oxygen content can reach very low values or zero, extinguishing aerobic aquatic organisms. Dissolved oxygen is the main parameter for characterizing the effects of water pollution [3; 13].

The pattern of oxygen distribution in aquatic ecosystems is, as a rule, inverse to carbon dioxide. When intense carbon dioxide consumption occurs in the euphotic zone due to photosynthesis, while considerable oxygen production occurs. On the other hand, in the aphotic zone, due to microbial activity (decomposition of organic matter), there is a high carbon dioxide production and corresponding oxygen consumption [14; 15].

The solubility of oxygen in water, as with all gases, depends on two main factors: temperature and pressure. Thus, as the temperature rises and the pressure decreases, there is a reduction and solubility of oxygen in water [16; 17; 13]. Some indirect factors may also be cited as controlling for dissolved oxygen concentration, such as the length of the thermal stratification period, the concentration of organic matter (dissolved and particulate) of the water, and the phytoplankton photosynthesis rate. Based on these properties it is concluded that tropical aquatic organisms have in principle less oxygen available than those of temperate lakes [12].

3.3 Thermotolerant Coliforms

Thermotolerant coliforms is one of the most widely used microbial indicators of water quality [18]. This parameter is based on the development of *Enterobacteriaceae* family bacilli, of fecal or environmental origin, within the temperature range 44.5 ± 0.2°C. Tolerance within this temperature range determines the differentiation between fecal (thermotolerant) and non-fecal (thermosensitive) subgroups [19; 20].

The *Enterobacteriaceae* family includes oxidase-negative, non-spore-forming bacteria of approximately 0.4-0.7 mm in size, characterized by the activity of the enzyme β-galactosidase (fermenting lactose at temperatures of 44º - 45ºC, with production of acid, gas and aldehyde) [22]. Four groups of these bacteria, including *Escherichia coli*, *Citrobacter*, *Enterobacter* and *Klebsiella*, are widely used as indicators of thermotolerant coliforms, distributed in different proportions in different environments, such as water, sewage, soil, vegetables and food. Of these, only *E. coli* is guaranteed to be present in humans and homeothermic animal feces with percentages of around 96 to 99%. The other kinds participate with percentages ranging from 3 to 8% in animal feces to 3 to 4% in human feces [19; 20; 23].

The determination of the presence of thermotolerant coliforms is of great importance as an indicator of fecal contamination, since even in waters of secondary and recreational contact, thermotolerant coliforms are considered to cause waterborne pathologies (**otitis externa**, gastrointestinal disorders characterized by diarrhea, **urinary tract infections**, pneumonia and meningitis), or indicative of the presence of other pathogens [24; 25].

3.4 Potential of Hydrogen (pH)

In pure water there is an albeit small amount of H and OH- ions in equilibrium with the water molecules. The basicity or acidity of a solution is often expressed in terms of ion concentration, H+ which is determined pH, which is defined as the negative logarithm of the hydrogen ion molar concentration [12].

In a natural environment, many factors can influence pH values, which makes it, despite its importance, one of the most difficult environmental variables to interpret. In most surface waters the pH is influenced by the concentration of H ions from carbonic acid dissociation, which generates low pH values and the reactions of carbonate and bicarbonate ions with the water molecule that raise the pH values to the alkaline range [26].

Most continental water bodies have a pH ranging from 6 to 8; however, one may encounter more acidic or more alkaline environments. In both cases, these ecosystems have also characteristic plant and animal communities [9].

Low pH lakes are often found in volcanic regions. The low pH of these ecosystems (<2) is mainly due to the presence of sulfuric acid and other mineral salts whose cations hydrolyze [12].

Aquatic ecosystems with high pH values are generally found in regions with negative water balance (where precipitation is less than evaporation); in regions where continental aquatic ecosystems are, to varying degrees, influenced by the sea (receive large contributions from carbonates and bicarbonates), and in karst regions (calcium rich regions) [26].

The importance of pH as a limiting factor for colonization of aquatic ecosystems by different organisms was first recognized by Thienemann (1918) [27]. This fact served as a basis for formulating a basic principle in ecology: “The more the living conditions of a biotope deviate from the optimal conditions for most organisms, the poorer will be the communities species, the more uniform and more typical they will be, and the greater the number of organisms in each species”.

The pH also influences the water treatment steps (coagulation and level of scalability/corrosivity) and the control of the operation of sewage treatment plants (anaerobic digestion).

3.5 Nitrogen

Nitrogen is one of the most important elements in the metabolism of aquatic ecosystems. This importance is mainly due to its participation in protein formation, one of the basic components of biomass. When present in low concentrations, it can act as a limiting factor in the primary production of aquatic ecosystems [28].

The main natural sources of nitrogen can be rain, organic and inorganic material and the fixation of molecular nitrogen within the lake itself. The increase of nitrogen in water is associated with the presence of domestic, industrial sewage and fertilizers. The predominant form of nitrogen may provide the pollution stage: recent pollution is associated with organic nitrogen or ammonia, while more remote pollution is associated with nitrogen in the form of nitrate [3].

Nitrogen is present in aquatic environments in various forms, for example: nitrate (NO), nitrite (NO), ammonia (NH_3), ammonium ion (NH_{4-}), nitrous oxide (N2O), molecular nitrogen (N2), dissolved organic nitrogen (peptides, purines, amines, amino acids, etc.), particulate organic nitrogen (bacteria, phytoplankton, zooplankton and detritus), etc. [12].

Among the different forms, nitrate, along with ammonium ion, play a great role in aquatic ecosystems, as they represent the main sources of nitrogen for primary producers [29].

High concentrations of the ammonium ion may have major ecological implications, such as: strongly influencing the dissolved oxygen dynamics of the environment and influencing the fish community, because at basic pH the ammonium ion becomes ammonia (free, gaseous), which depending on its concentration may be toxic to these organisms [12].

One of the first studies to determine the effects of nitrogen on natural environments and its association with other parameters was performed by Trussel (1972) [30], concluding that in these environments the concentration of ammonia very rarely reaches lethal levels. For these levels to be reached, high pH (>9.0), temperature (>260ºC) and low oxeduction potential values must occur simultaneously.

3.6 Phosphorus

Phosphorus is an important element in fundamental processes of living metabolism, such as: energy storage (it forms an essential fraction of the ATP molecule) and cell membrane structure (through phospholipids) [12].

In most continental waters phosphorus is the main limiting factor of its productivity. Moreover, it has been pointed as the main responsible for the artificial eutrophication of these ecosystems [28; 31; 32].

All forms of phosphorus present in natural waters, both ionic and complexed, are in phosphate form which can be divided into five main forms: particulate phosphate (P - particulate), dissolved organic phosphate (P – dissolved organic), dissolved inorganic phosphate or orthophosphate or reactive phosphate (P-ortho), total dissolved phosphate (P - total dissolved) and total phosphate (P - total) [3].

From a limnological point of view, all forms (also called fractions) and phosphate are important, however, P-ortho assumes greater relevance because it is the main form of phosphate assimilated by aquatic plants. Thus, its quantification in limnological evaluations becomes indispensable [33].

Phosphate present in continental aquatic ecosystems originates from natural and artificial sources. Among natural sources, drainage basin rocks, especially apatite, constitute the basic source of phosphate for continental aquatic ecosystems. The release of phosphate from the crystalline form of the primary rock minerals occurs through its breakdown by weathering [12].

Other natural factors that allow phosphate input can be pointed out, such as: particulate matter present in the atmosphere and phosphate resulting from the decomposition of organisms of allochthonous origin. The most important artificial sources of phosphate are domestic and industrial sewage and industrial particulate matter contained in the atmosphere [12].

3.7 Biochemical oxygen demand

The reduction in dissolved oxygen concentration is the main problem of water pollution and occurs because of the respiratory activity of bacteria to stabilize organic matter. Therefore, the presence of organic matter in water can be assessed by measuring oxygen consumption. To indicate the oxygen consumption or demand required to stabilize organic matter in water, the parameters BOD (Biochemical Oxygen Demand) and COD (Chemical Oxygen Demand) are used [22].

The difference between BOD and COD is in the type of stabilized organic matter: while BOD refers exclusively to mineralized organic matter by activity of microorganisms, COD also encompasses the stabilization of organic matter by chemical processes based on the fact that some organic compounds are oxidized by oxidizing chemicals considered strong in acidic environments. Therefore, the COD value is always higher than the BOD value.

As COD values are generally higher than those found for BOD, in laboratory tests, COD is determined first, and the results serve as guidelines for establishing dilutions for BOD testing. The relationship between COD and BOD values indicates the amount of organic matter that can be biologically stabilized. This demand is referred conventionally to a period of five days, since the complete stabilization of organic matter requires a longer time, and at a temperature of 20°C [34].

Both BOD and COD are expressed in mg/L. Most values found in the national literature report organic loading in terms of BOD, which is, between the two, the most commonly used parameter to characterize domestic sewage and industrial effluents [35].

In unpolluted natural environments, BOD concentration is low (1 mg/L to 10 mg/L) and can reach much higher values in bodies of water subject to organic pollution, usually due to the receipt of domestic sewage or animal breeding. Effluents from industries that process organic matter (dairy, breweries, refrigerators) have BOD values in the order of tens or even hundreds of grams per liter [22].

3.8 Temperature

The change in water temperature can be caused by natural (mainly solar) or anthropogenic (industrial waste and machine cooling water) sources and can significantly influence the aquatic environment and its biota by interfering with the speed of chemical reactions, biochemical and physiological activities of organisms and the solubility of substances [36].

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The thermal regime of a body of water is a crucial factor for ecosystem quality. In Brazil, aquatic environments generally have temperatures in the range of 20°C to 30°C. However, in colder regions, such as in the south of the country, winter water temperatures can reach values between 5°C and 15°C, reaching, in some cases, the freezing point [22].

Temperature also influences other physicochemical parameters of water, such as surface tension and viscosity. Aquatic organisms are affected by temperatures outside their thermal tolerance limits, which impacts their growth and reproduction. The higher the temperature, the lower the surface tension that serves as a substrate for the life of small organisms [37; 38]. Viscosity reflects its flow resistance inversely proportional to temperature, which means that a hot water is less viscous than a cold water, interfering, among other factors, in the mobility of small organisms and sedimentation of suspended particles [39].

Due to the high specific heat of water, aquatic environments are quite stable with respect to temperature. Despite the thermal stability, the water bodies present temperature variations throughout the day (to a greater or lesser extent depending on the local morphoclimatic domain) and the seasons of the year. However, discharging effluent at high temperatures can have a significant impact on water bodies. Regarding water for human consumption, high temperatures increase the prospects of rejection to use [40].

3.9 Turbidity

Turbidity is the parameter that represents the occurrence of light passing through water due to the presence of suspended particles, giving it a turbid appearance [41] expressed by means of turbidity units (also called Jackson or nephelometric units) [22]. The aesthetically undesirable aspect caused by increased turbidity is derived from the presence of suspended particles in different dimensions, ranging from colloids to coarse suspensions, including organic detritus, algae, bacteria and plankton that compromise light passage, causing their scattering and absorption.

Aquatic biological communities are strongly affected by turbidity variation, since their increase, for example, reduces photosynthesis from submerged rooted vegetation and algae, and may therefore suppress fish productivity [12]. In addition, high turbidity directly affects domestic, industrial and recreational water use.

In Brazilian water bodies, due to geological characteristics and high rainfall rates in most drainage basins, turbidity is particularly high because rainfall on erodible soils can carry clay particles, silt, sand, rock fragments and metal oxides from the soil.

In lakes and dams, where there is little runoff, turbidity is lower. The natural turbidity of water in these environments ranges from 3 to 500 Units (NTU). According to CONAMA Resolution (2005), for class 3 freshwater bodies, the turbidity limit is 100 NTU (turbidity unit). In filtered water, turbidity assumes a sanitary and not merely aesthetic indicator function. For potability purposes, turbidity should be less than one unit, ensuring the effectiveness of filtration, disinfection and absence of pathogens.

3.10 Total (solid) residue

Residues or Solids are all materials suspended or dissolved in water, in domestic or industrial waste. Total residue is the matter that remains after evaporation, drying or calcination of the water sample for a given time and temperature. In general, the drying, calcining and filtration operations define the various fractions of solids present in water (total, suspended, dissolved, fixed and volatile solids) [42].

Total solids can be classified into total suspended solids and total dissolved solids, and according to the thermal treatment performed on the sample, the solids can be further fragmented into "fixed" and "volatile" terms, which are determined gravimetrically, an analytical procedure based on the difference between dry mass and wet mass, in relation to the sample volume disposed in the test at different temperatures [43; 44].

Although turbidity and total solid parameters are intuitively associated, they are not at all equivalent. A stone, for example, placed in a glass of clean water, gives to that environment a high concentration of total solids, but its turbidity may be practically null [22].

4. Conclusion

Lakes and their basins are unique and integrated units, so all processes and problems are interconnected. Thus, this ecosystem must be managed without jurisdictional limitation and various policy instruments need to be introduced.

It is understood that this management should be institutionalized through policies and systems, which define and give effect to the roles of governments, civil society and the private sector, at the national, regional and global levels.

Water in nature presents a series of dissolved compounds that adhere to it through the atmosphere, soils, rocks and the decomposition of organic matter. These compounds are responsible for the characteristics of water even in its natural condition [3]. Because of the long response time, impacts are sustained for a long time, solutions take time, and changes are often gradual and invisible. Long-term monitoring commitment based on reliable geochemical analysis is required.

The complex response dynamics in these ecosystems also make responses to impacts unpredictable, making scientific involvement in linking problems to their cause's indispensable, with a long-term and politically strong commitment. Based on this, water classification systems fall into two main types: those concerned with the amount of pollution present and those concerned with communities living on macroscopic or microscopic organisms.

The assignment of a numerical value based on physicochemical variables should consider the conformity of local water and climate characteristics and their adaptations to the analysis, although presenting satisfactory results, masks a variety of conditions that occur in a water course, e.g. presence of pathogenic microorganisms. Although its synthesis capacity makes it an important instrument with strong public utility, it is noteworthy that the WQI represents a quality index, not an instrument for evaluating public service.

One of the current major challenges in environmental quality management is to reach a balance between the activities that generate economic development and the preservation of the environment. This challenge has been translated through the concept of sustainable development, which aims to meet the needs of the current generation, without compromising the ability to meet the needs of future generations [3].

Integrated watershed management should seek to address challenges for sustainable use of lake and river resources. The term 'integrated management' refers to the simultaneous consideration of all relevant management factors, including scientific and socioeconomic ones. The scientific elements are highlighted in their importance as input of theoretical support and technical information, the socioeconomic are major components of lake management and are, therefore, factors that should be aligned with the sustainable use of services of that ecosystem and a given basin [10].

Although there is much to be celebrated regarding the legal framework and the progress made, huge challenges remain to be met in order to achieve effective integrated management. These challenges refer to issues of great complexity that will still deserve enormous efforts to overcome integration of water management with environmental management; integration of quantity and quality aspects; integration of surface and groundwater management; and especially the integration of water resources policy with sectoral policies [3]. Efforts should be made, however, towards an innovative approach generating new management practices and policies.

The systemic model of water resources management adopted for Brazil is still in the process of improvement, despite the great and current advances achieved since the beginning of its implementation. The challenges pointed out, at no time, question the model's postulates and premises, nor do they advocate their revision. They only point out that, given the country's diversity and the different levels of water resources commitment along its territory, it is reasonable to think of multiple views and adaptation care that are not yet given [3].

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