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Water quality assessment of La Tembladera wetland in Ecuador using Water Quality Index

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Abstract. In developing countries, tropical wetlands are essential for human livelihoods since they storage and provide freshwater for domestic, industrial, and agricultural uses. Unfortunately, tropical wetlands are subjected to anthropogenic impacts, such as direct discharge of municipal, industrial and livestock wastewater, leading to water pollution, and thus, affecting directly or indirectly people's health. Therefore, water quality assessment of these unique ecosystems using practical tools, such as Water Quality Index (WQI) is of great importance. This study aims to assess the water quality of one tropical Ramsar wetland La Tembladera for human consumption in wet and dry tropical seasons using WQI. This index was calculated using the following physical, chemical, and biological parameters: potential hydrogen (pH), turbidity, electrical conductivity (EC), dissolved oxygen (DO), biological oxygen demand (BOD₅), chloride ions (Cl⁻), sulfates (SO₄²⁻), nitrates (NO₃⁻), iron (Fe²⁺), *Escherichia coli* (*E. coli*), and *Clostridium perfringens* (*C. perfringens*). The WQI calculations revealed high values for the wet and dry tropical seasons, displaying values of 416.63 and 427.1, respectively. The obtained values indicate that the water of La Tembladera wetland is unsuitable for human consumption. These results might be valuable for legislative decision-makers to develop further recommendations and plans to improve the water quality, either for drinking purposes or other needs.

Keywords: drinking water quality, developing country, water quality index, Ramsar wetland, La Tembladera, Ecuador

Introduction

Worldwide, wetlands are considered the most productive ecosystems. They occur as ecotones, between terrestrial and aquatic ecosystems, thus, they possess unique hydrological and soil conditions, biodiversity, etc. [1]. Wetlands play a significant role in environmental processes, such as flood control, local and regional temperature influence, retention of soils and sediments. Further, they provide habitat for unique flora and fauna, and supply important ecosystem services that contribute to human livelihood, for instance, storage and retention of freshwater for domestic, industrial, and agricultural uses; food production (fish, fruits, and grains); production of logs, fuelwood, peat, fodder, etc. [2].

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Due to their extraordinary ecosystem services and population growth, wetlands are often subjected to anthropogenic impact: agriculture land conversion, overexploitation of their resources, and direct discharge of municipal, industrial and livestock wastewater [3–5]. As a result of uncontrolled discharges of municipal and industrial effluents, a significant change in the ecosystem can occur, resulting in water pollution, eutrophication, pathogen development, and physicochemical changes in surface waters. Thus, an epidemiological danger situation can arise [6]. People's health in Ecuador directly depends on water quality because surface water bodies, including wetlands, are the main and the only water sources for human needs and consumption. At present, the threat of waterborne diseases and epidemics is still a serious problem for developing countries, including Ecuador [7]. Besides, poor water quality has a negative impact on aquatic life preservation [8].

The resilience of wetland ecosystems is provided by self-purification potential, however this resilience can significantly change under extra anthropogenic load. This situation is observed in La Tembladera wetland, which is one of the 19 Ramsar sites in Ecuador since 2011, consequently acquiring international status for protection and rational use of resources. The main wastewater sources in La Tembladera are households, cattle excretion discharges, and agricultural runoff [8]. Four coastal communes (San Jose, La Florida, Las Crucitas, San Agustin) are situated along the western zone of the wetland, with an approximately population of 635 people [9]. Due to the absence of a sewerage system, whose construction started only in July 2018, the domestic wastewater is discharged directly or through pipelines (constructed by local residents) into the wetland's water zone and its surrounding territory. Also, the adjacent territory to the object is mainly used for cattle grazing, as well as for short-cycle crops (tomato, pepper, watermelon, rice, sugar cane, cocoa, lemon, pitahaya, mango) and pasture grasses [4; 10]. La Tembladera supplies water for Brahman and Brownsuiz cattle (around 812 head of cattle), whose physiological excretions are also discharged into the wetland [9].

Therefore, water quality assessment of these unique ecosystems has become crucial to determine the pollution level in the first instance, and after that, to develop and implement preventive actions and sustainable resource management plans in developing countries [11]. A practical and simple tool to describe the water quality, at a given time, is the estimation of the water quality index (WQI) based on weights for an individual parameter. The WQI integrates several physical, chemical, and biological parameters. The first WQI was developed by [12], since then, different modifications and methods for the calculation have been proposed by different national and international organizations [13]. WQI allows to assess and demonstrate changes (annual cycles, spatial and temporal variations) in water quality and to identify water trends even at low concentrations [11; 13]. Therefore, the aim of this study was to evaluate the water quality of La Tembladera wetland for human consumption in wet and dry tropical seasons using WQI.

Materials and methods

Object of study. The present study was carried out in La Tembladera wetland, which is a continental-type freshwater wetland located in the southwestern coast of Ecuador, canton Santa Rosa, in the province El Oro (3° 29' 26" S, 79° 59' 43" W;

12–32 m a.s.l.). The region has a tropical climate, which is characterized by the alternation between rainy or wet (winter) season, whose monthly average precipitation is 170 mm, and dry season (summer) with an average precipitation of 10.2 mm [5; 10].

The water body area occupies 1,471.19 ha, its permanent water area is 104 ha [10]. The flooded area depends on the season, the water surface may reach 188 ha during the wet season, and the land surface 1,199 ha. The wetland monthly average water temperature is 25.82 °C. La Tembladera is mainly fed by the Santa Rosa and Arenillas rivers through a canals system: Estero Pinto ($0.041 \text{ m}^3 \cdot \text{s}^{-1}$) and San Agustín ($23.43 \text{ m}^3 \cdot \text{s}^{-1}$), respectively [5]. During the wet season, the wetland annual average flow rate is $14.50 \text{ m}^3 \cdot \text{s}^{-1}$, the monthly maximum is $61.0 \text{ m}^3 \cdot \text{s}^{-1}$, and the minimum $0.20 \text{ m}^3 \cdot \text{s}^{-1}$; while during the dry season the flow rate is usually $0 \text{ m}^3 \cdot \text{s}^{-1}$ [5].

La Tembladera belongs to the life zone “Tropical Spiny Mountain” (in Spanish language: “Monte Espinoso Tropical”). For much of the year the wetland water table is near the land surface, hence the vegetation is adapted to moisture conditions, for instance, water lettuce (*Pistia stratiotes*), water hyacinth (*Eichhornia crassipes*), common cattail (*Typha latifolia*) and white lotus (*Nymphaea lotus*) [14]. This ecosystem supports 43 plants species, is the habitat for 80 waterfowl birds, 14 fish species, 8 reptiles and 20 mammals [10].

Water sampling and laboratory analysis. The water sampling was carried out in August 2018 and April 2019, corresponding to the dry and wet tropical seasons, respectively, at three sites with different levels of anthropogenic load: the site No. 1 was located near a small village, whose wastewater and wastes were discharged into the wetland territory; the site No. 2 was located at 20 m from the wetland shore, being a vegetation-free water surface; the site No. 3 was near a boat dock, an area with coastal vegetation and aquatic macrophytes, the area covered by macrophytes on the water surface was 40%. A total of 63 water samples were taken. During the field survey, air temperature in August was 24.1 °C, while in April was 27.8 °C. The water quality analysis was conducted regarding water temperature (T), potential hydrogen (pH), turbidity, electrical conductivity (EC), dissolved oxygen (DO), biological oxygen demand (BOD₅), chloride ions (Cl⁻), sulfates (SO₄²⁻), nitrates (NO₃⁻), Fe²⁺, *Escherichia coli* (*E. coli*), and *Clostridium perfringens* (*C. perfringens*).

The water temperature was measured at a depth of 0.2–0.5 m using an alcohol thermometer with an accuracy of 0.1 °C. Potential hydrogen was determined using Mettler Toledo and Expert-001 pH meters. Turbidity was measured using spectrophotometric method. DO was measured using Bante821 portable Dissolved Oxygen Meter. Biochemical oxygen demand was estimated using standard methods described by the Russian regulatory document NDP 10.1:2:3.131-2016. Sulfates were measured using conductometric titration method. Chloride ion concentrations were determined using the Mohr method. Nitrates were measured using the potentiometric method. Iron ion was measured using flame atomic absorption spectrometry. The electrical conductivity and nitrates data for the dry season were acquired from a scientific study [15]. Bacteria of the *E. coli* group were determined by membrane filters method, and for identifying *C. perfringens* the Omelyansky medium was used.

Water quality index. WQI was determined based on important human health parameters. Water quality standards for human consumption and domestic uses from “Unified Text of Environmental Secondary Normative or TULSMA of Ecuador” (in Spanish language: “Texto Unificado de Legislación Secundaria de Medio”) [16]

and also standards recommended by the World Health Organization (WHO) [17] were used. The algorithm for the WQI calculation includes 4 steps [18].

1. For each parameter, a weight (W_i) from 1 to 4, according to different experts in previous studies was assigned. In terms of importance for drinking purpose, the value “1” is the least important, and the value “4” is the most important. The mean values of the given weights for each parameter are presented in Table 1 and these values were used for the calculations. Due to the scarce information about weight values for Clostridia in the literature, the weight has been proposed by the author.

Table 1

Assigned weight values from the literature to the water quality parameters

Reference	pH	Turbidity	DO	EC	BOD ₅	SO ₄ ²⁻	Cl ⁻	NO ₃ ⁻	Fe ²⁺	<i>E. coli</i>
[19]	1	4	4	4	3	2	1	2	–	3
[19]	1	–	4	–	2	–	–	3	–	4
[19]	4	–	4	4	4	–	–	–	–	–
[19]	4	2	4	2	3	–	–	–	–	–
[19]	1	–	4	1	3	2	1	2	–	–
[19]	1	2	4	2	3	2	1	2	–	–
[19]	4	2	4	2	3	–	1	–	–	4
[11]	1	2	4	4	3	–	1	2	–	3
[19]	2.1	2.4	4	2.7	3	–	–	2.2	–	–
[20]	4	–	–	–	–	3	3	4	3	–
[21]	4	2	4	2	–	–	3	4	–	–
[22]	4	1	4	4	–	–	1	–	–	–
Proposed weight	2.6	2,2	4	2.8	3	2.3	1.5	2.7	3	3.5

2. The relative weight was calculated using the following equation:

$$RW = W_i / \sum W_i, \tag{1}$$

where W_i is the assigned weight to each parameter, and RW is the calculated relative weight.

The Table 2 summarizes the calculated relative weights.

Table 2

Standards and relative weights for different water quality parameters

Parameters	Units	Standards		Wet season		Dry season	
		Ecuador	WHO	Weight (W_i)	Relative weight (RW)	Weight (W_i)	Relative weight (RW)
pH	–	6–9	6.5–8	2.6	0.10441767	2.6	0.107438
Turbidity	NTU	10	5	2.2	0.08835341	–	–
DO	mg·L ⁻¹	6	–	–	–	4	0.1652893
EC	μS·cm ⁻¹	–	400	–	–	2.8	0.1157025
BOD ₅	mg·L ⁻¹	2	–	3	0.12048193	–	–
SO ₄ ²⁻	mg·L ⁻¹	250	250	2.3	0.09236948	–	–
Cl ⁻	mg·L ⁻¹	250	250	1.5	0.06024096	1.5	0.0619835
NO ₃ ⁻	mg·L ⁻¹	10	50	27	0.10843373	2.7	0.1115702
Fe ²⁺	mg·L ⁻¹	0.3 – 1.0	0.3	3	0.12048193	3	0.1239669
<i>E. coli</i>	1 ml	–	1	3.6	0.14457831	3.6	0.1487603
<i>C. perfringens</i>	1 ml	–	1	4	0.16064257	4	0.1652893
				Σ = 24.9	Σ = 1	Σ = 24.2	Σ = 1

3. For each parameter, a quality range scale was calculated using the equation (2). For pH and DO the equation (3) was used.

$$Q_i = (C_i / S_i) \times 100, \tag{2}$$

$$Q_i = (C_i - V_i / S_i - V_i) \times 100, \tag{3}$$

where C_i is the value of the water quality parameter obtained from the analyzed water samples, S_i is the value of water quality parameter reported by WHO or Ecuadorian standards, Q_i is the quality rating, and V_i is the ideal value of 7.0 for pH and 14.6 for DO.

Equations (2) and (3) ensure that $Q_i = 0$ when the analyzed parameter is absent in the water sample, and $Q_i = 100$ when the value of the parameter is equal to its permissible concentration in accordance with the standards. Therefore, the higher the value of Q_i , the more polluted the water.

4. At the final stage, each sub-index parameter (S_{li}) was calculated using the expression (4). The WQI was estimated employing the equation (5). For both seasons, the obtained WQI was classified as <50 – excellent; 50–100 – good; 100–200 – poor; 200–300 – very poor; >300 – unsuitable for drinking purposes [19].

$$S_{li} = RW \times Q_i, \tag{4}$$

$$WQI = \sum S_{li}. \tag{5}$$

Results and discussion

The Table 3 shows the mean values (M) of the analyzed physical, chemical, and biological parameters, and the obtained values of WQI. For both seasons, the calculated WQI reveals that water is unsuitable for human consumption according to the water quality classification: in the wet season the WQI is 416.63. The variables that increase this value are turbidity, Fe^{2+} , *E. coli* and *C. perfringens*, since their Q_i values are over 100, which means that they do not meet the standards for water quality. Analogously, the variables that increase the WQI (427.1) in the dry season are the Q_i values over 100 of DO and microbiological parameters.

Table 3

WQI of La Tembladera wetland in Ecuador

Parameters	Units	Wet season			Dry season			
		M	Q_i	S_{li}	M	Q_i	S_{li}	
pH	–	6.51	98	10.23	6.67	66	7.09	
Turbidity	NTU	25.5	510	45.06	–	–	–	
DO	mg·L ⁻¹	–	–	–	2.004	146.46	24.21	
EC	μS·cm ⁻¹	–	–	–	325	81.25	9.40	
BOD ₅	mg·L ⁻¹	1.58	79	9.528	–	–	–	
SO ₄ ²⁻	mg·L ⁻¹	1.55	0.62	0.057	–	–	–	
Cl ⁻	mg·L ⁻¹	3.15	1.26	0.076	127.8	51.13	3.17	
NO ₃ ⁻	mg·L ⁻¹	0.41	4.1	0.445	0.57	5.7	0.64	
Fe ²⁺	mg·L ⁻¹	0.45	150	18.072	0	0	0	
<i>E. coli</i>	1 ml	10.6	1.060	153.25	11.27	1.127.33	167.70	
<i>C. perfringens</i>	1 ml	11.2	1.120	179.92	13	1.300	214.88	
				WQI = 416.63	WQI = 427.1			

The calculated sub-indices revealed that exists a slightly difference of Fe^{2+} , *E. coli* and *C. perfringes* between seasons, while for pH, Cl^- , and NO_3^- no significant differences were detected. In the dry season, the biological parameters were higher than in the wet season, whereas there was less Fe^{2+} concentration in the dry season (Figure).

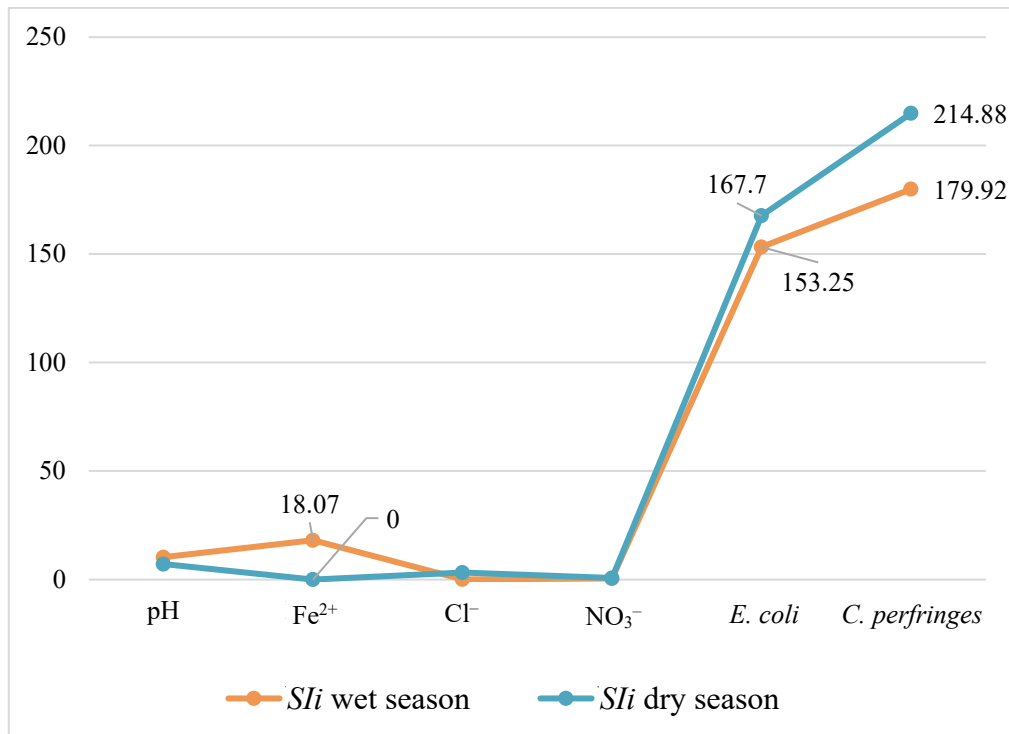


Figure. Calculated SII for different water quality parameters of La Tembladera wetland in Ecuador

Physical-chemical parameters. In the dry season the average water temperature was 25.6 ± 0.40 °C, while in the wet season was 33 ± 0 °C. According to Ecuador's water quality standards these values are within the acceptable limits.

Potential hydrogen. The mean for pH was 6.51 in the wet season and 6.67 in the dry season, thus water can be classified as weakly acidic. These values are within the WHO and Ecuadorian standards, hence, the Q_i values for this parameter are less than 100, leading to a low WQI. The SII for pH doesn't show notable difference between seasons. The sub-index is slightly higher in the wet season, however, in summer a value of 6.37 was observed at site No. 1, which is under the WHO guidelines.

Turbidity. The average turbidity was 25.5 NTU in the wet season, which exceeds the WHO guidelines by 5 times and the Ecuadorian by 2.5 times. The maximum obtained value was 42 NTU in the wetland shore (near the boat dock) and the minimum was 9 NTU at site No. 2. The values of turbidity are significantly high, which might be explained by the constant rainfalls and the consequent runoff that washes solid matter from the adjacent territory toward the water body. In this season, the average precipitation reaches 170 mm [5].

Dissolved oxygen. The average values below 3 mg/l, which are under the permissible Ecuadorian limits, and the high assigned weight to this parameter influ-

enced the high *SIi* of 24.21. Low concentrations of DO are a result of the limited transfer from the air to the water mirror due to a dense vegetation of free-floating aquatic macrophytes (*Pistia stratiotes* and *Eichhornia crassipes*). They cover approximately 75% of the water surface during the dry season [8]. Besides, due to the typical saturation and flood conditions of wetlands, where anaerobic conditions predominate, the DO is usually low.

Electrical conductivity. The value of EC at the water surface was $200 \mu\text{S}\cdot\text{cm}^{-1}$ and increased to $450 \mu\text{S}\cdot\text{cm}^{-1}$ in the bottom waters. The average value of this parameter does not contribute to the WQI, nevertheless the EC values indicate that water was considerably ionized, since the dissolved solids amount in water determines the electrical conductivity. Therefore, the detected values might be due to a significant dissolved solids concentration in water.

Biological oxygen demand. Low concentrations of biodegradable organic matter were detected. The values match with Ecuadorian norms on water quality and suggest that exists low load of domestic wastes and wastewater, cattle excretion discharge and vegetal detritus. According to The National Water Secretariat of Ecuador (SENAGUA), in 2018 one inhabitant consumed in average 249 liters of water per day, then taking into account the coastal communes population of the wetland (635 people), and a return coefficient of 80%, the volume of domestic discharge into the wetland is about 126.5 m^3 per day, that is $45,540 \text{ m}^3$ per year. Since wetlands are natural filters of several pollutants, involving microbiological and vegetation processes, it can be assumed that La Tembladera controls the given load of organic matter.

As regards sulfates and nitrates, the *SIi* of NO_3^- between seasons does not show significant differences. The obtained *SIi* for these anions is due to the detected low concentrations, which can be explained by the fact that in the surrounding area, where the samples were taken, no evidence of intensive agriculture was observed. This indicates that agriculture activities do not contribute to SO_4^{2-} and NO_3^- inputs, and do not represent a hazard for human health.

Chlorides. The obtained *Qi* values for Cl^- are very low (<100), which indicates that the mean values from the samples comply the standards. In the dry season the Cl^- concentrations were higher (127.8) than in the wet season (1.26). High concentrations of chloride in summer could be related to sewage mixing, organic waste of animal origin, temperature increases, and evapotranspiration by water [5]. Moreover, Cl^- can enter to the ecosystem by atmospheric deposition, agricultural and irrigation discharges. High concentrations of chloride also indicate a decrease of aerobic bacteria, which is reflected in the low concentrations of DO.

Iron. Concentrations of Fe^{+2} over permissible limits were detected in water samples of the wet season, hence the WQI increased for this season. This fact represents a danger not only for humans, but also for cattle, as this wetland water is their main source of drinking water. High iron concentrations in drinking water may arise from natural levels in ground water, run-off from mining or other contaminating sources. La Tembladera receives water inputs from the Santa Rosa river by the canal Bellavista and the Estero Pinto, and artisanal mining is conducted in the microbasin of this river [8; 9]. However, this cannot be considered direct iron source since the detected concentrations are low. The main iron sources at the sampling sites can be related to the boat dock, where corrosion of iron containing metals was observed during the field survey.

Biological parameters. Concentrations of *E. coli* and *C. perfringens* were significantly high in both seasons. The detected *E. coli* in all the water samples confirms a recent and constant fecal contamination. The high concentration of *C. perfringens*, particularly in water samples at sites 2 and 3, is an indicator of fecal contaminants accumulation at the bottom of the wetland. These results corroborate the constant water contamination due to domestic wastewater and cattle excretion discharges into the water body. The detected fecal contamination indicators do not comply with the standards for water quality. Therefore, due to their high weights and strict guidelines, these microbiological parameters contributed the most to increase the WQI.

Conclusion

The WQI calculations revealed high values for both seasons, the wet and dry tropical seasons present values of 416.63 and 427.1 respectively. The parameters that increased the WQI in the rainy season are turbidity, Fe^{2+} , *E. coli*, and *C. perfringens*; while in the summer, DO and microbiological parameters. This means that these variables did not meet the standards for water quality since their Q_i values were over 100, hence based on the equation (3), a value equal to its permissible concentration has a $Q_i = 100$, thus, the expression $Q_i > 100$ indicates an increase of the pollutant concentration. As expected, the water quality assessment using a water quality index proves that the water of La Tembladera wetland is unsuitable for human consumption. These results confirm previous findings [5], where a Simplified Index of Water Quality (SIWQ) was used to assess the water quality of La Tembladera in 2016. The obtained values range from 10 to 39, determining the water quality as very poor and unsuitable for drinking purposes.

This study has led us to conclude that the application of Water Quality Index is a simple and useful tool for evaluating water quality of tropical wetlands. This is needed in Ecuador and other developing countries of tropical regions, as lack of information about anthropogenic impacts on wetlands water resources, due to a non-existent specific budget for wetland management, is a current problem. Therefore, the obtained results in this study might be valuable for legislative decision-makers to develop further recommendations and projects to improve water quality, either for drinking purposes or other needs. Also, this research is beneficial in order to bring together diverse stakeholders interested in wetlands protection. Since La Tembladera provides water for human needs and consumption, agricultural irrigation systems, and drinking supply for cattle, water resources monitoring and assessment are suggested to be regularly carried out.

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Bio note:

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Научная статья

**Оценка качества воды
водно-болотного угодья Ла Тембладера в Эквадоре
на основе индекса качества воды WQI**

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Аннотация. Тропические водно-болотные угодья имеют важное значение для жизнедеятельности человека, поскольку они хранят и обеспечивают пресную воду для бытового, промышленного и сельскохозяйственного использования, особенно в развивающихся странах. Несмотря на это, водно-болотные угодья часто подвергаются антропогенным воздействиям, таким как прямой сброс муниципальных, промышленных и животноводческих сточных вод, что приводит к загрязнению воды и в свою очередь прямо или косвенно влияет на здоровье людей. Именно поэтому оценка качества воды этих уникальных экосистем с использованием практических инструментов, таких как индекс качества воды WQI, имеет большое значение. Целью исследования являлась оценка качества воды для использования в питьевых целях водно-болотного угодья Ла Тембладера в разных тропических сезонах, применяя WQI. Проведен анализ воды и расчет индекса по некоторым физико-химическим и биологическим параметрам: потенциаль-

ный водород (рН), мутность, электропроводность, растворенный кислород, биохимическое потребление кислорода (БПК₅), хлорид-ионы (Cl⁻), сульфаты (SO₄²⁻), нитраты (NO₃⁻), железо (Fe²⁺), *Escherichia coli* (*E. coli*) и *Clostridium perfringens* (*C. perfringens*). Выявлены высокие значения как для влажного, так и для сухого сезонов: 416,63 и 427,1 соответственно. Таким образом, качество воды водно-болотного угодья Ла Тембладера может быть оценено как неудовлетворительное для применения в качестве питьевой для населения. Полученные результаты будут полезны лицам, принимающим законодательные решения, а также для разработки дальнейших рекомендаций и проектов по улучшению качества воды, как для питьевых целей, так и для других нужд.

Ключевые слова: качество питьевой воды, развивающиеся страны, индекс качества воды, водно-болотное угодье Рамсар, Ла Тембладера, Эквадор

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