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Impact of Tourism on the Water Quality of the El Oconal Lagoon, Pasco, Peru: A Study for Conservation Porpuses

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Abstract: El Oconal Lagoon suffers from anthropic pressure and environmental deterioration. Therefore, this study aimed to evaluate the water quality and pollution indicators of El Oconal Lagoon for conservation purposes. The study was conducted during the winter and spring of 2023, as well as the summer and fall of 2024. The main tributary, the drainage, two coastal station near a tourist center, and one stations at the pelagic zone were selected as study stations. The most important physical (temperature, electrical conductivity, transparency, turbidity, and total dissolved solids), chemical (pH and dissolved oxygen), and microbiological parameters (thermotolerant coliforms and phytoplankton) were evaluated. Water quality was assessed according to Peruvian water quality standards, Palmer pollution and trophic status indexes. El Oconal Lagoon showed anthropic impact, mainly at sites near touristic areas, where thermotolerant coliforms ranged between 252 and 1550 MPN·100 mL^{-1} and *Escherichia coli* between 4 and 102 MPN·100 mL^{-1}, in both cases with levels higher than the values established in the water quality standards. Likewise, the Palmer pollution index showed lower contamination in the pelagic zone, moderate contamination in the tourist area, and probable high contamination in the drainage. The lagoon was found to be in a mesotrophic condition. These results provide evidence that the competent authorities must manage wastewater in the lagoon to preserve the health of its ecosystem.

Keywords: Tourism; Wastewater; Anthropic pressure; Environmental deterioration

1 Introduction

Lakes and lagoons near urban areas are undergoing significant environmental degradation due to intense anthropic pressure [1], with multiple pollution sources (agriculture, urban wastewater, tourism, etc.) adversely affecting the ecosystem and its biodiversity [2].

Lagoons are essential for preserving biodiversity and delivering ecosystem services, even though they are smaller than lakes [3]. The integrity of the aquatic environment may be at risk, though, because they are smaller bodies of water and are therefore more vulnerable to changes in their physical, chemical, and biological characteristics brought on by anthropic or natural factors [4].

Changes in land use, air temperature, precipitation, anthropic activity in the watershed, and the growth of nutrients from agricultural, urban, or industrial sources are some of the elements that might impact the water quality in lagoons [5]. The transportation from surrounding areas and discharge from rivers, nutrients in lagoons rise during the rainy season, according to research on seasonal fluctuation in nutrient concentrations [6]. The latter can result in significant eutrophication by interacting and intensifying the detrimental impacts on water quality [7].

Research on bacteria [8], phytoplankton [9, 10], zooplankton [11], macroinvertebrates [12], and fish [13] has shown that anthropic activities near lakes and lagoons can change the composition of biological communities, contributing to poor water quality and ecosystems.

Ecological processes and aquatic life in the environment are endangered by declining water quality, which negatively impacts biodiversity [14]. Along with the possible ripple effects this may have on the rest of the ecosystem, environmental degradation affects aquatic organisms, biodiversity, and habitat availability [15].

Water quality monitoring is crucial for assessing the state of lagoons and establishing conservation-related management strategies because of their significance. El Oconal Lagoon is an important tourist destination; however, there is little documentation about its water quality or conservation [16]. The study aimed to assess the impact of the tourism on the water quality of El Oconal Lagoon in Pasco, Peru, for conservation purposes.

2 Material and Methods

2.1 Study Area

The study was carried out between coordinates $10°45'18''$ S and $75°16'50''$ W in the Pasco area, Villa Rica district, Oxapampa province, Peru, and the Andes Mountains near El Oconal Lagoon (Figure 1). For each area of interest, one sample station was taken into consideration (Table 1).

Table 1. Stations by sampling areas in El Oconal Lagoon

Sampling Station	Sampling Zone	Latitude S	Longitude W
E1	Primary tributary	$10°45'04.41''$	$75°16'59.01''$
E2	Drainage	$10°44'50.47''$	$75°16'27.79''$
E3	Restaurant	$10°44'58.71''$	$75°16'21.92''$
E4	Touristic center	$10°45'03.04''$	$75°16'24.36''$
E5	Pelagic zone	$10°45'05.59''$	$75°16'14.34''$

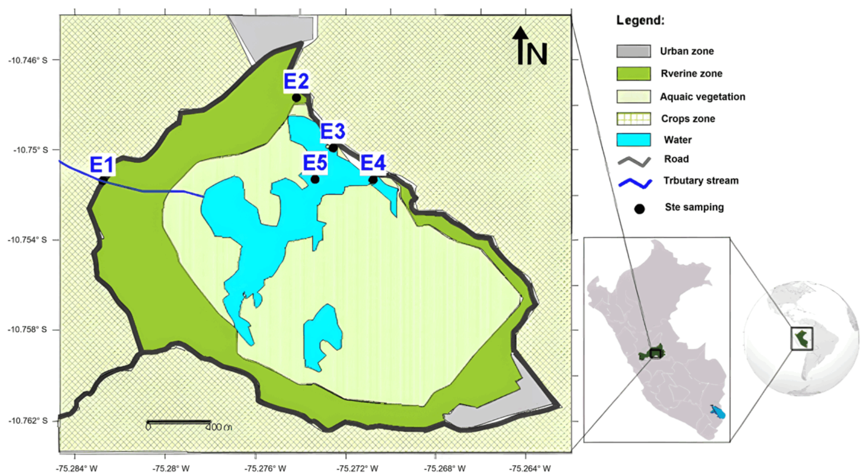

Figure 1. Location of sampling stations in El Oconal Lagoon, Pasco, Peru

The lagoon is a popular tourist attraction in Peru's central jungle that during 2023 received more than 18,000 tourists (80% nationals, 12% locals, and 8% foreigners) [17].

Of the selected study sites, E1 station sampling is the main tributary, in its course to exist several local residences, stations E3 and E4 correspond to areas adjacent to two tourist sites, the first had a collapsed septic tank with excess liquid that drained directly to the shore of the lagoon, and the second discharged its wastewater through pipes directly into the body of water. Likewise, abundant proliferation of "water hyacinth" (*Eichhornia crassipes*) was observed between the two sites.

Tourist activities and local residences are absent in the southern and western sectors of the lagoon, so that was not monitored. This study prioritized touristic and residential areas.

This study was conducted between August 2023 and March 2024, examining the biological parameters of El Oconal Lagoon.

2.2 Data Collection

The parameters in this study were selected according to the Water Quality Standards (WQS) from Peru established in the Supreme Decree No. 004-2017-MINAM [18]. A Lutron WA2017SD multiparameter meter was used to measure pH, temperature (T), electrical conductivity (EC), and total dissolved solids (TDS). A Lutron TU-2016 turbidimeter was used to measure turbidity (TU). Ammonia (NH_3) was measured using the test kit HI3824 (Hanna).

Standardized techniques were used in the laboratory to identify *Escherichia coli* (ECOLI) and thermotolerant coliforms (TC) (American Public Health Association-APHA, 1995). Finally, a Secchi disk was used to assess transparency (TRAN). The sampling was performed according to the "National Protocol for Monitoring the Quality of Surface Water Resources" [19], where T, DO, TSD, pH, EC, TU, and TRA were recorded four times in each monitoring, and TC, ECOLI, NH_3 only once. A single monitoring event was carried out during each seasonal period.

A 20 μm mesh plankton net was used to gather phytoplankton at the surface. Important taxonomic guides [20–24] were consulted during the species identification process.

2.3 Data Analysis

Following Zar's [25] instructions, statistical analyses were conducted using R software [26], which included nonparametric Kruskal-Wallis tests, boxplot diagrams, and principal component analysis (PCA).

2.4 Water Quality Assessment

A primary criterion for assessing the health of the aquatic ecosystem was the use of the main water quality standards established for Peru. Protozoa, viruses, or antibiotic-resistant bacteria are not included in the quality standards defined in Supreme Decree No. 004-2017-MINAM [18], which does not reference viruses or resistant bacteria. Although helminths are included, they were not considered in this study due to project limitations.

Complementary, the trophic state was also ascertained by means of Carlson's trophic state index [27] and transparency. Organic pollution was assessed using the Palmer pollution index [28] (Table 2).

Table 2. Pollution index based on the presence of algae genera [28]

Genera	Index	Genera	Index
Anacystis	1	*Micractinium*	1
Ankistrodesmus	2	*Navicola*	3
Chlamydomonas	4	*Nitzschia*	3
Chlorella	3	*Oscillatoria*	5
Closterium	1	*Pandorina*	1
Cyclotella	1	*Phacus*	2
Euglena	5	*Phormidium*	1
Gomphonema	1	*Scenedesmus*	4
Lepocinclis	1	*Stigeoclonium*	2
Melosira	1	*Synedra*	2

Palme's pollution index considers 0–10 = low organic pollution, 10–15 = moderate pollution, 15–20 = probable high organic pollution, 20 or more = confirmed high organic pollution.

3 Results

3.1 Physical, Chemical, and Microbiological Parameters

Based on the average physical parameter data (Table 3). The T ranged between 19.0 and 24.7 °C, EC between 160 and 370 $\mu S^{-1} cm^{-1}$, TDS between 110 and 227 mg·L^{-1}, TU between 5.7 and 15. 5 NTU, and TRAN between 1.16 and 1.18 m, that to determine mesotrophic condition of the waterbody according to Carlson's trophic state index [27]. Across all physical parameters assessed, a statistically significant difference ($p < 0.05$) was discovered across stations.

Regarding the chemical characteristics (Table 3), the DO ranged between 4.1 and 5.8 $\mathrm{mg \cdot L^{-1}}$, the pH between 2.9 and 4.4, and the $\mathrm{NH_3}$ was constant across all stations (except for the E3 in $\mathrm{NH_3}$). Between the sites under evaluation, no discernible variations were found in these metrics.

The TC concentration varied between 10.5 and 1550 MPN·100 $\mathrm{mL^{-1}}$ with respect to the microbiological parameters assessed (Table 3). The concentration of ECOLI also varied, ranging from 4 to 121 MPN·100 $\mathrm{mL^{-1}}$.

Table 3. Mean values and standard deviations of the main physical, chemical, and biological parameters of El Oconal Lagoon

Parameters	Sampling Stations				
	E1	E2	E3	E4	E5
Physicals					
T°C	19.0^{b}	23.5^{a}	25.2^{a}	24.7^{a}	24.5^{a}
EC μS·cm^{-1}	370^{b}	166^{a}	173^{a}	168^{a}	160^{a}
TDS mg·L^{-1}	247^{b}	119^{a}	110^{a}	113^{a}	111^{a}
TU NTU	15.5^{c}	10.7^{a}	11.3^{b}	5.7^{a}	7.7^{b}
TRAN cm	Sd	Sd	122	119	115
Chemicals					
DO mg.L^{-1}	5.8	4.4	4.1	4.1	4.6
pH	3.5	3.6	4.4	3.0	2.9
$\mathrm{NH_3}$ mg·L^{-1}	0.2	0.2	0.3	0.2	0.2
Microbiologicals					
TC MPN·100 mL^{-1}	1550	255.5	1550	252	10.5
ECOLI MPN·100 mL^{-1}	121.0	17.5	23.5	102	4.0

Note: Different superscript letters indicate statistically significant differences ($p \leqslant 0.05$)

According to WSQ category Conservation of aquatic environments – subcategory lagoons and lakes from Peru (Supreme Decree No. 004-2017-MINAM), DO, pH, TC and ECOLI presented values that did not comply. The DO in E3 and E4 sites was minor in 0.9 mg·L^{-1} respecting quality standard value of 5 mg·L^{-1}, E2 in 0.6 mg·L^{-1} and E5 in 0.4 mg·L^{-1}; only E1 presented acceptable value. The pH was minor between 1.6 (E3) and 3.1 (E5) units respecting WQS minimum value (6). According to TC values 200 MPN·100 mg·L^{-1} established as SWQ for surface waters intended for recreation category, values in E1 and E3 exceeded 1350 MPN·100 mg·L^{-1}, while E2 and E4 in 55.5 and 52 MPN·100 mg·L^{-1}, respectively. The E5 station sampling presented an acceptable value. The ECOLI was present in all stations assessed, the WQS in their Conservation of aquatic environments—subcategory lagoons 0 and lakes established 0 MPN·100 mg·L^{-1}. The concentrations of TC and ECOLI explain the negative effect of wastewater without treatment evacuee of touristic centers and local residences.

PCA analysis showed that the tributary (E1) correlated with TC, ECOLI, EC, TDS, and DO, indicating that household wastewater was contaminating the sector under evaluation. The E3 showed a correlation with $\mathrm{NH_3}$, suggesting that wastewater from tourist attractions (restaurants) and riverbank residences is a source of contamination. Additionally, the presence of algae belonging to the Dinophyta and Bacillariophyta groups was also correlated with this location. In addition to phytoplankton groups including Chlorophyta, Cyanophyta, and Euglenophyta—two more markers of organic contamination—the drainage site (E2), and stations E4 and E5 exhibited a link to T and TRAN (Figure 2).

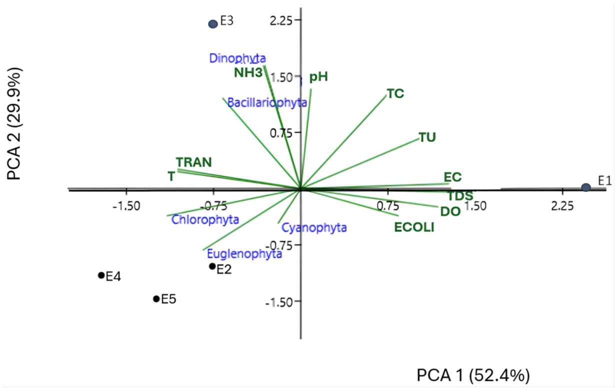

Figure 2. PCA analysis of the physical, chemical, and microbiological parameters assessed of El Oconal Lagoon

3.2 Assessment of Organic Pollution

Low organic pollution was found in the E1 and E5 sites; moderately polluted waters were found in the E3 and E4; and likely high organic pollution was found in the E2 (Table 4).

Table 4. Assessment of pollution in El Oconal Lagoon

Genera	E1	E2	E3	E4	E5
Closterium	-	1	-	-	-
Euglena	5	5	5	5	5
Gomphonema	-	1	-	-	-
Lepocinclis	-	1	1	-	1
Navicola	3	3	3	3	3
Oscillatoria	-	5	-	-	-
Phacus	-	-	2	2	-
Phormidium	1	-	1	-	-
Scenedesmus	-	4	4	-	4
Synedra	-	2	-	2	2
Palmer pollution index	9	22	16	12	15

4 Discussion

The water temperature in the El Oconal Lagoon was higher than 22°C, a normal value for a tropical body of water found in the high jungle of central Peru, slightly lower than that recorded in the Cashibocoha lagoon in Ucayali [29]. This parameter was very important because it regulates the dynamics of biological processes in the aquatic ecosystem [30].

According to Riofrío et al. [29], the DO in the water decreases when the temperature rises, being this warm water lagoon; however, contrasted with water quality standards, it is not very consistent since the established value is 5 $mg{\cdot}L^{-1}$ [18].

In our study, the DO concentrations were low in stations with touristic activity, that presented notables TC and ECOLI concentrations. Bacterial communities experiment spatial and temporal variability, related with changes in the concentrations of dissolved oxygen and organic matter in the water column [31], where the low oxygen levels are associated with high consumption by bacteria in waters with a high concentration of organic matter [32], thus indicators of poor-quality water [33].

Organic pollution in our work was evaluated with the use of Palmer's method [28], based on the presence of phytoplankton bioindicator species, a simple method of low cost, but current [34], and by microbiological analysis. According to the results of this study, the water presented high organic pollution in the E2 stations sampling, and probable high organic pollution in the E3 station sampling. This context represents a great environmental risk of eutrophication and deterioration of the waterbody [35].

Electrical conductivity is an indicator that, together with the concentration of total dissolved solids, are good indicators of water quality [36], and in this case, values below 1000 $\mu S{\cdot}cm^{-1}$ indicate acceptable waters according to the environmental quality standard for water [18].

The pH of the water of the El Oconal Lagoon was acidic (≤ 5), typical of Amazonian tropical black waters [37] due to the degradation of organic matter. However, according to the environmental quality standard for water [18], they were below the determined value. Low values of pH in our study could be related with acidification, a worrying problem in the freshwater, associated with high discharge of nitrogen compounds from wastewater [38], that modify important ecological process as recycling of organic matter, food webs and lake productivity, with negative impacts on hydrobiological communities [39, 40].

Respecting coliforms evaluated in the water of the Oconal lagoon, they were found at levels that exceeded the values determined in the environmental quality standard for water (S.D. No. 004-2017-MINAM). Indicators of wastewater pollution were observed in the E1 (Tributary) and riverside areas of the E3 (touristic restaurant), and E4 (touristic center). Our report showed that tourist activity negatively impacts the aquatic ecosystem of the El Oconal Lagoon. In this regard, similar bodies of water in rural areas where wastewater is not managed have also observed the problem, and more so when there is a high concentration of people for tourist activities [41]. The studies [42, 43] emphasized that lentic bodies of water, naturally endowed with scenic beauty, are important tourist attractions with high concurrence of visitors, but these places are suffering environmental deterioration with degradation of ecosystems and biodiversity, due to deficient environmental management.

Likewise, from the analysis of the phytoplankton community, contamination by organic matter was evidenced from the Palmer index [28], which is very reliable to evaluate water quality and contamination [44] in freshwaters.

On the other hand, water transparency made it possible to determine a mesotrophic state for El Oconal Laggon, associated with nutrient enrichment by direct discharge of wastewater of touristic and urban centers [16], and agricultural activity [17]. This state can aggravate eutrophic conditions and cause a serious imbalance and alteration of the lagoon ecosystem [45]. The high nutrient concentration explains the abundant proliferation of floating aquatic plants such as the "water hyacinth" [46], phytoplankton, and fecal coliforms; the latter, of risk to the health of locals and visiting tourists [47]. It should be noted that responsible tourism management [48] is important to conserve freshwater ecosystems that are of tourist interest.

It is important to periodically carry out sanitary control of urban establishments and water quality to avoid the risk of organic and microbiological pollution in freshwater [49]. So, there is a necessity to implement efficient environmental management programs.

5 Conclusions

This research found that the poor state of the El Oconal Lagoon was due to pollution from tourist areas and urban growth. This was linked to poor wastewater treatment and sanitation methods.

Moving forward, continuous monitoring of water quality is essential. Therefore, the relevant authorities required assessing the quality condition of the lagoon in critically identified zones, and to determine new sampling sites that require assessment to ensure the public and ecosystem health.

Author Contributions

Conceptualization, B.B.R.S., H.J.C.P., M.A.C., L.F.V.C., and D.L.B.; methodology, B.B.R.S., H.J.C.P., A.M.Z.T., S.F.G., L.F.V.C., and D.L.B.; validation, A.M.Z.T. and S.F.G.; formal analysis, S.F.G.; investigation, B.B.R.S., H.J.C.P., A.M.Z.T., S.F.G., M.A.C., L.F.V.C., and D.L.B.; resources, A.M.Z.T. and J.M.G.M.; data curation, A.M.Z.T. and J.M.G.M.; writing-original draft preparation, B.B.R.S. and H.J.C.P.; writing-review and editing, A.M.Z.T., S.F.G., M.A.C., J.M.G.M., and L.F.V.C.; visualization, J.M.G.M. and D.L.B.; funding acquisition, B.B.R.S. and H.J.C.P. All authors have read and agreed to the published version of the manuscript.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

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Conflicts of Interest

The authors declare that they have no conflicts of interest.

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