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First Physico-Chemical and Traditional Characterisation of Lake Tseny, Northwest Madagascar

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Abstract

This study was designed to assess the biophysical structure, traditional practices and water quality of Lake Tseny in northwest Madagascar. The lake was divided into five zones: the central zone and the littoral zones (east, north, west and south). Transects and direct observation were used to estimate submerged tree and vegetation cover. Information on local traditions was collected through interviews with key people and visits to sacred sites. Water quality was assessed during the rainy and dry seasons, 2017–2018. Samples were taken twice a day, in the early morning and evening, at randomly selected points at intervals of 400m. The aquatic vegetation covered over 75% of the lakeshore. Most of the submerged tree trunks were recorded along the western area. Five sacred sites associated with eight forms of traditional taboos to reduce the potential source of water pollution were recorded in and around the lake. The lake is bowl shaped. The water was warm (T° 25.3 - 35.6 °C), slightly alkaline (pH 7.1 - 8.5), well oxygenated (DO 4.63 - 9.6 mg/l) and less mineralised (EC 71.70 - 122.40 µS/cm). We found a seasonal difference in water quality between the rainy and dry seasons. Results showed spatial variation in water quality between zones. A comparison of the mean values with water quality standards showed that Lake Tseny has good water conditions for domestic purposes and suitable habitats for aquatic fauna throughout the year. These preliminary results provide reference data on the lake's characteristics. Due to the increasing human activities in the area, regular monitoring of water quality and physical characteristics should be carried out.

Keywords: Lake Tseny, Madagascar, Biophysical structure, Traditional practice, Physico-chemical parameters, Water quality

Introduction

Human life and the survival of aquatic species depend heavily on water sources, including lakes and rivers. Water sources provide many services, such as use for domestic and agricultural purposes, refuge and natural habitat for aquatic species, and recreational opportunities. Many factors continue to threaten freshwater ecological integrity (Munir et al., 2016). In recent years, increasing human population, food demand, land conversion and fertiliser use have led to accelerated degradation of many freshwater resources (Jayakumar et al., 2009; Mushini et al., 2012). Various physicochemical parameters have been used to determine surface water quality for drinking purposes (Joshi et al., 2009; Kumar & Sinha, 2010), to analyse water pollution (Zinsou et al., 2016), and for bio-ecological and chemical relationships (Mbalassa et al., 2014; Pârvulescu et al., 2011).

In Madagascar, hydrobiological studies have assessed the physico-chemical parameters of different water sources as indicators of water body status, water quality, and the origin of the variability of water minerals (Rabemanana et al., 2005; Rasolofomanana, 2009; Rasolofonirina et al., 2018) and interspecific relationships (Rasoloariniaina et al., 2016). Lake Tseny, located in the northwestern part of the island, is a wetland of considerable importance for both human well-being and biodiversity conservation (Andriafidison et al., 2011). The lake is home to seven native and endemic fish species, one of which, *Paretroplus menarambo*, is classified as critically endangered. This species was thought to be extinct in the wild (Loiselle & De Rham, 2003), but was recently confirmed to occur in Lake Tseny (Andriafidison et al., 2011). The lake also harbours Madagascar's big-headed

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turtle *Erymnochelys madagascariensis* and the Madagascar fish eagle *Haliaeetus vociferoides*. Both species are critically endangered. Lake Tseny is an important source of income and food from fishing activities and water for domestic use (e.g., drinking water, washing, bathing). The study area is known for its intense agricultural activity and overuse of chemical pesticides. It is one of the main producers of black-eyed peas in Madagascar. Due to the high demand, producers are increasing their efforts in terms of area under cultivation and the use of pesticides. No scientific study of water quality in the area has been carried out to date. Baseline and reference data on the lake's characteristics are needed to plan for biodiversity conservation and sustainable human use. This study aims to assess: (1) traditional beliefs and practices in and around the lake (2) physical characteristics and (3) water quality for aquatic species and human use.

Materials and Methods

Study site

Lake Tseny is located in the Sofia region, Port-Bergé district, northwest Madagascar (Figure 1). Lake Tseny covers an area of 641 hectares. The undulated water surface depends on the wind direction and the seasons. From May to October, during the dry season, the easterly 'varatraza' winds blow from east to west, pushing the water in the same direction. But in the rainy season, from November to April, the westerly 'talio' winds push it in the opposite direction (from west to east). The average annual temperature is 26.4°C. The average recorded rainfall varies from 1098 mm to 2053 mm.

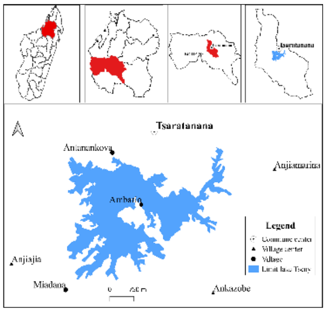

Figure 1. Study site

Data collection

In situ water sampling was carried out in September and December 2017 and in April and September 2018. The representative sample points were randomly selected using the transect method (CCME, 2011). However, we selected each point at 400 meters intervals using GPS by canoe. Fifty-eight (58) points were recorded and measured (Figure 2). Seasonal measurements were made at the same points. Based on local knowledge, the lake is divided into five fishing areas or zones: North, South, West, East, and Central zones

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(Figure 2). The boundaries of the areas were mainly determined based on the cardinal direction and indigenous considerations about the fishing places, passed from generation to generation in informal way.

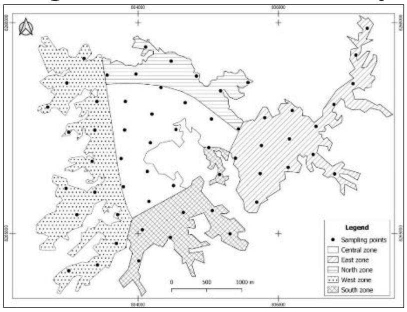

Figure 2. Lake zones and sampling point locations

Sampling was carried out twice a day: between 05:00–08:00 in the morning and 15:00–18:00 in the evening. In this study, physico-chemical parameters such as water surface temperature, pH, electrical conductivity (EC) and total dissolved solids (TDS) were measured using a portable multi-parameter meter kit Apera instruments SX823-B. Water depth was measured using a depth mate portable water sounder. Dissolved oxygen (DO) and oxygen saturation (O2) were measured using an YSI's EcoSense DO200A handheld DO meter. Ammonium, nitrate and nitrite analyses were also carried out using a API Freshwater Master Test Kit. Sampling tubes were properly cleaned with water before the next analysis. In addition, environmental conditions (temperature and relative humidity) were recorded using special data loggers placed in the peninsula village in the middle of the lake.

The description of the vegetation cover in the littoral zones was carried out by measuring the macrophyte covering the shoreline. Measurement locations were randomly selected using the transect method (CCME, 2011) during the selection of water sampling locations. However, the shoreline locations close to (approximately 20m) and perpendicular to the sampling locations were selected. Percent coverage of vegetation was estimated within 20 m horizontal line in the littoral zone using direct observation. Macrophyte percent coverage was determined according to the CCME (2011) categories:

- Absent 0%
- Sparse 1-30%
- Moderate 30-60%
- Dense 60-100%.

The pattern groups of vegetations all through the lake were also recorded using direct observation. A submerged woods assessment was carried out in October 2017, during the low water level by recording the location, number and diameter of sunken woods using GPS and a canoe.

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Key informant interviews were conducted to collect data on sacred sites and associated local taboos. Key informants include fokontany 'smallest administrative subdivision' or village leaders and elders, as well as community members who are familiar with the lake and its surroundings, taboos and traditional culture.

Data processing and statistical analysis

The normality test has shown nonnormal distribution of data. Nonparametric statistical test variables were used. The Kruskal-Wallis test was used to compare variations in physico-chemical parameters between lake zones (north, south, east, west and central) and the Mann-Whitney test for seasonal differences (dry and wet) was performed in R 3.3.2. Spearman's correlation was used to determine the relationships between the physico-chemical parameters.

Results

Biophysical characteristics of the Lake Tseny

The shape of Lake Tseny shows many bays, three tributary inlets (Ambalambato in the north, Begidroa in the east and Ambarijeby in the south) and one main outlet (Ambinany in the north). The Anjombony and Ambavany Ankazobe rivers are the two main tributaries of the lake. The tributaries flow into the lake mainly during the flood season and transport a large amount of organic and inorganic material. The aquatic vegetation covered more than 75% of the littoral zone, mainly Phragmites sp. (POACEAE). The lake shows a spatial distribution of pattern groups of aquatic vegetation (*Phragmites* sp.) (Figure 3).

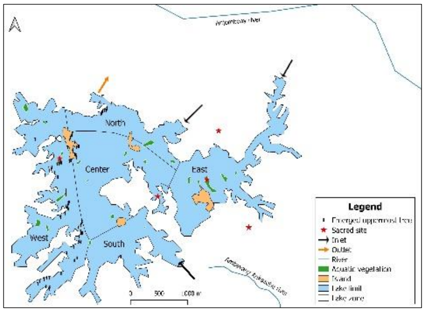

Figure 3. Spatial distribution of aquatic vegetation, submerged tree and island

Submerged trees

A total of 115 submerged wood items were recorded at 81 sites. The topmost branches protrude from the water surface (Figure 4).

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Figure 4. Emerged uppermost branches

The results show a spatial variation in the distribution of submerged wood within the lake. However, 82 submerged trunks were recorded at 53 sites on the western shore, followed by 22 submerged trunks at 19 sites in the central zone. In addition, 10 pieces of submerged wood were recorded at eight sites in the north and only one piece in the south. No submerged wood was recorded on the east bank. The diameter of submerged tree trunks ranged from 0.1 to 0.6 m, with a mean of 0.24 ± 0.09 m. A significant difference in wood diameter was found between lake zones (Kruskal-Wallis test: $df = 3$, $p < 0.05$). The largest submerged wood was found in the central zone and the smallest in the northern shore (Figure 5).

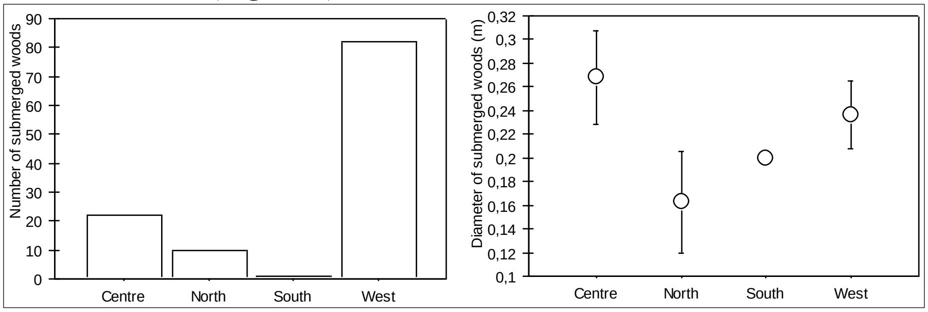

Figure 5. Variation in emerged uppermost tree trunks between lake zones

Taboos and traditional practices

Five sacred sites were surveyed in and around Lake Tseny (Figure 3). These sites have high spiritual value and are the sites of important traditional ceremonies. Eight main taboos were reported: 1) no pig or pork in and around the lake, 2) no menstruating women passing through the lake, 3) no defecating or urinating anywhere on the lake, 4) no motorised canoe, 5) no washing dishes in the lake, 6) no fishing on Tuesday, 7) no passing the lake while drunk, 8) be physically clean before fishing.

Key informants reported that these taboos are enforced in and at the villages around the lake. The penalty for breaking a taboo is the sacrifice of a

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zebu. Breaking the taboo is reported to have a supernatural sanction, such as low fishing catch and/or death by drowning.

Physico-chemical water characteristics

The data (Means, std.Err, min and max values) for water physico-chemical parameters are presented in Table 1.

Table 1. Basic statistics summary for the general physico-chemical parameters (for all data together)

Water parameters	Mean	Std. Err	Min	Max
Depth (m), N= 232	4.04	0.09	1.4	7.4
Temperature (°C), N= 231	28.65	0.15	25.30	35.60
pH, N= 232	8.00	0.02	7.05	8.54
Electrical Conductivity: EC (µS/cm), N= 231	96.03	0.84	71.70	122.40
Total Dissolved Solid: TDS (mg/l), N= 232	68.27	0.60	51.10	84.90
Dissolved Oxygen: DO (mg/l), N= 232	7.62	0.06	4.63	9.60
Oxygen saturation: O_2 (%), N= 232	98.33	0.77	59.90	120.40
Nitrate: NO3- (mg/l), N= 208	0.09	0.05	0.00	5.00
Nitrite: NO2- (mg/l), N= 232	0.01	0.01	0.00	1.00
Ammonium: NH4- (mg/l), N= 232	0.23	0.01	0.00	1.00

The results from the statistical variation test in physico-chemical parameters are shown in figures 6 and 7.

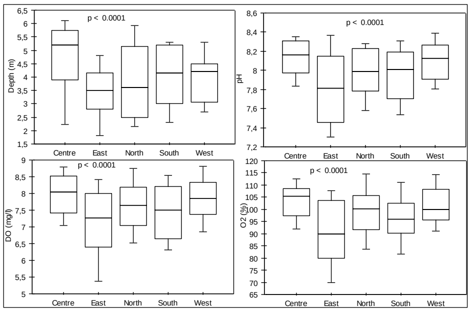

Figure 6. Variation in physico-chemical parameters (p =Kruskal Wallis value test) between lake zones (centre, east, north, south and west)

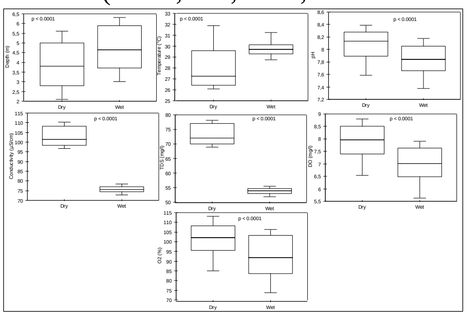

Figure 7. Variation in physico-chemical parameters (p =Mann Whitney value test) between seasons (Dry and wet)

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The lake showed very significant variation in water depth between the lake zones and seasons. However, the lake is bowl-shaped, significantly deepest in the central zone and shallowest in the littoral zone, especially in the eastern zone (Kruskal-Wallis test: $\chi2 = 31.48$, df = 4, $p < 0.0001$). The water was significantly deeper in the wet season than in the dry season (Mann-Whitney test: $z = -4.16$, $p < 0.0001$). The water level in the wet season (April) was 1m higher than in the dry season (November-December).

Water surface temperature was warm but not significantly different between lake zones (Kruskal-Wallis test: $\chi2 = 4.61$, df = 4, $p > 0.05$), indicating uniform conditions for temperature. But a significant difference between seasons was found (Mann-Whitney test: $z = -5.73$, $p < 0.0001$), with the wet season being warmer than the dry season.

The water was slightly alkaline. The pH value varied significantly between the zones of the lake (Kruskal-Wallis test: $\chi2 = 27.24$, df = 4, $p < 0.0001$). The highest pH (8.12 ± 0.03) was recorded in the central zone and the lowest (7.81 ± 0.05) in the littoral zone. A significant difference in water pH between seasons was found (Mann-Whitney test: $z = -5.57$, $p < 0.0001$). However, it was higher in the dry season (8.07 ± 0.29) than in the wet season (7.80 ± 0.31).

The results showed no spatial difference in conductivity between the lake zones (Kruskal-Wallis test: $\chi2 = 3.12$, df = 4, $p > 0.05$). Thus, water conductivity is relatively constant across the lake areas. A strong significant difference in conductivity between seasons was found (Mann-Whitney test: $z = -11.39$, $p < 0.0001$). Higher conductivity was recorded during the dry season (102.82 ± 5.88 µS/cm) than during the wet season (75.79 ± 2.00 µS/cm).

There was no significant difference in TDS between the lake zones (Kruskal-Wallis test: $\chi2 = 3.35$, df = 4, $p > 0.05$). A similarity in water TDS was found throughout the lake. Our results showed highly significant variations in TDS between seasons (Mann-Whitney test: $z = -1.39$, $p < 0.0001$), and higher water TDS was observed in the dry season (73.09 ± 4.03 mg/l)) than in the wet season (53.84 ± 1.33 mg/l).

Dissolved oxygen (DO) concentration showed a spatial significant difference between the lake zones (Kruskal-Wallis test: $\chi2 = 23.64$, df = 4, $p < 0.0001$). However, DO was highest in the central lake (7.97 ± 0.09 mg/l) and lowest in the littoral (7.08 ± 0.15 mg/l). There was also a significant variation in DO between seasons (Mann-Whitney test: $z = -6.75$, $p < 0.0001$), and it was higher in the dry season (7.86 ± 0.86 mg/l) than in the wet season (6.91 ± 0.85 mg/l). Oxygen saturation (O_2) is a function of DO and showed significant variation between lake zones and seasons.

Our results showed no spatial difference in nitrogen components (nitrate, nitrite, and ammonium) between lake areas (Kruskal-Wallis test: $\chi2 <$

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7.15 for all components, df = 4, $p > 0.05$) nor between seasons ($z < 0.7$ for all components, $p > 0.05$).

Correlation between water physico-chemical parameters

The results from Spearman's *r* correlation showed the correlation between physico-chemical parameters (Table 2).

Table 2. Correlation matrix between physico-chemical parameters of Lake Tseny: *p < 0.0001. D: Depth (m); T°: Temperature (°C); EC: Electrical conductivity (µS/cm); TDS: Total Dissolved Solid (mg/l); DO: Dissolved oxygen (mg/l); O_2: Oxygen Saturation (%); NO_3^-: Nitrate (mg/l); NO_2^-: Nitrite (mg/l); NH_4^-: Ammonium (mg/l).

	D	T°	pH	CE	TSD	OD	O2	NO3-	NO2-
T°	0.018								
pH	0.021	0.001							
EC	0.074	0.002	0.034						
TDS	0.07	0.002	0.038	*0.997					
DO	0.007	0.066	*0.703	0.033	0.037				
O2	0.027	0.007	*0.743	0.025	0.029	*0.849			
NO3-	0.001	0.024	0.002	0.028	0.029	0.006	0.003		
NO2-	0.003	0.08	0.016	0.03	0.03	0.000	0.016	0.364	
NH4-	0.001	0.02	0.007	0.006	0.006	0.031	0.016	0.111	0.093

Fluctuations of ambient conditions

Our results from the temperature and humidity data loggers showed the fluctuation of air conditions during the study period. The average temperature was 27.35 °C, with a minimum of 24.23 °C in July and a maximum of 30.16 °C in November (Figure 8). Relative humidity values varied throughout the year. The average relative humidity was 63.2%, with a minimum of 53.0% recorded in January. It reached a maximum of 73.4% in March.

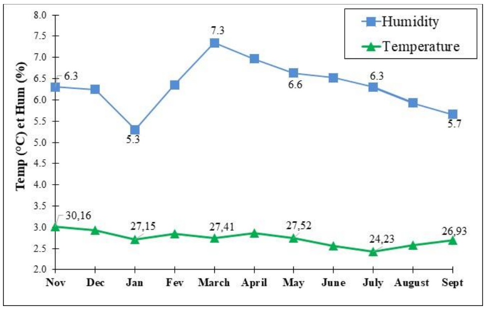

Figure 8. Temperature and humidity fluctuations during the present study

Discussion

Physical habitat of lake Tseny

Aquatic vegetation covered large littoral zones and numerous groups of aquatic vegetation were distributed throughout the lake. The most

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submerged tree trunks were recorded along the western lake. Our findings corroborate those of Andriafidison et al. (2011), who reported that the western area of the lake contained permanently submerged woods around which *P. menarambo* (a native and critically endangered fish species) was frequently netted. It was reported that the physico-chemical conditions of the western lake, especially around the submerged tree, influenced the habitat used by *P. menarambo* (Randrianandrianina unpublished). De Rham & Nourissat (2003) reported that the *Paretroplus* species are substratum spawners and require a solid surface to lay their eggs. In addition, Angermeier & Karr (1984) documented that many fish are sensitive to the effects of woody debris on habitat and food availability and are more closely related to the benefits of camouflage. The physical characteristics of the lake represent and provide essential habitats for aquatic species, including fish.

Importance of local traditions in Lake Tseny

Various forms of taboos and traditional prohibitions governed the lake Tseny. These prohibitions regulate human activities to minimise direct and indirect negative impacts on water quality by limiting potential anthropogenic pollution and to reduce pressure on fisheries resources by limiting the number of fishing days. In Madagascar, there has been a growing interest in integrating local traditions into modern conservation and management plans (e.g. Lingard et al., 2003). The traditional customs in and around lake Tseny were more weakly respected than reported by Cinner (2007) and Rabearivony et al. (2008) (Randrianandrinina unpublished).

Ambario village traditional authority asserted that to establish a lake uses and socio-cultural harmonies, the rite of purification of water should be accomplished, while the ceremony celebrates at the sacred site requires a zebu sacrifice (Randrianandrianina unpublished). To maintain the good water quality for aquatic life and human well-being through healthy aquatic ecosystem services, management implication should focus on development of the strategic plan considering the sociocultural aspect, involving the traditional authority.

Water physico-chemical characteristics

Due to rainfall, a significant difference in water depth was found between the seasons. The peak rainfall was in March (see Figure 8). The difference in water level in March may be greater than 1m the level in November-December due to the peak of precipitation. However, in terms of water depth, the research was biased by the inaccessibility of the study site in March due to the flood season when many rivers merged and overflowed, making access impossible.

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Table 3 shows that all physicochemical parameters meet water quality standards for potability and suitable to sustain aquatic species.

Table 3. Standard limit values of drinking water and suitable for aquatic life

Physicochemical parameters (Present study)	Limit for drinking water		Limit suitable for aquatic life
	Acceptable limit	Restricted limit	
Temperature 25.30 to 35.60°C (28.65±0.15 °C)	25 to 30°C (WHO, 1984)	-	20°C à 32°C (Boyd, 1998; Lowe-McConnel, 1987)
pH 7.05 to 8.54 (8.00±0.02)	6.5 to 8.5 (WHO, 2011; WaterAid, 2004)	4.5 - 10 (WaterAid, 2004)	6.5 and 8.2 (Murdoch et al., 2001)
Conductivity 71.70 to 122.40 µS/cm (96.03±0.84 µS/cm)	2 000 µS/cm (WaterAid, 2004)	3 400 (WaterAid, 2004)	
Total dissolved solid 51.10 to 84.90 mg/l (68.27±.060 mg/l)	Less than 300 mg/l (OMS)	1 000 mg/l (Madagascar Code Eau, 1999)	400 mg/l (Boyd & Tucker, 1998)
Dissolved oxygen 4.63 to 9.60 mg/l (7.62±0.06 mg/l)	Minimal of 5 mg/l (Bhanja & Ajoy 2000)	-	-
Ammonium 0 to 1 mg/l (0.23±0.01 mg/l)	17 mg/l (EPA, 2013)	-	-
Nitrate 0 to 5 mg/l (0.09±0.05 mg/l)	50 mg/l (WHO, 2011; WaterAid, 2004)	100 (WaterAid, 2004)	-
Nitrite 0 to 1 mg/l (0.01±0.01 mg/l)	0,1 mg/l (WaterAid, 2004)	3 (WaterAid, 2004)	-

The lake temperature was similar to the mean air temperature at the study site (data from the data logger in this study) and was related to the difference in air temperature between seasons, which was slightly higher in the rainy period (28.58 °C) than in the dry period (28.07 °C), indicating that the water temperature is related to the ambient temperature of the study area and period (Tfeil et al., 2018). The comparison with Lake Kinkony, the northwestern lake, showed similar values varied between 29.8°C and 34.7°C (Rasoloariniaina, 2010). The constant surface temperature throughout the lake is in agreement with the results of Charrada (1992) who showed that the water surface temperature was homogeneous throughout the lake.

The alkalinity range of the lake may be due to the photosynthesis of high-density vegetation, a process that absorbs carbon dioxide (CO_2) from the water and produces oxygen (Pedersen et al., 2013). As the plants remove CO_2, the water becomes more alkaline and the pH rises. The pH of Lake Tseny was similar to that of Lake Kinkony and ranged from 7.6 to 8.19 (Rasoloariniaina, 2010). Furthermore, the seasonal variation in pH, lower in the hot-wet period

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could be explained by the higher temperature, which accelerates chemical reactions and increases metabolic activities of organisms (Chapman et al., 1996; Usharani et al., 2010), consuming the dissolved oxygen in the water and releasing CO_2, and decreasing the pH level. The spatial difference in the pH level, which was lower in the littoral zones, implied that the decomposition process was transforming high organic matter (plant debris from a large amount of aquatic vegetation on the shoreline) and lowering the pH level. Higher organic matter levels are associated with lower pH levels (Taylor & Middleton, 2004).

A lower EC value could be due to the fact that the natural sediments are poor in organic matter and less affected by mineralisation processes (Delmas, 1980). Northwestern Lake Kinkony with EC values between 169 and 298 µS/cm (Rasoloariniaina, 2010) showed higher values than Lake Tseny. Agarwal & Kannan (1996) reported that the deterioration of water quality was mainly due to the concentration of TDS. However, water with high TDS is generally of poorer drinking quality. Lower EC and TDS in the rainy season could be due to the high inflow of water during rainfall, which contributes to water dilution.

The high value of the DO content may be due to both the photosynthesis of the high density of vegetation, such a process absorbing carbon dioxide (CO_2) from the water and producing oxygen (Pedersen et al., 2013), and the wind blowing that increases the exchange of atmospheric oxygen with the water surface (Kateb et al., 2018). The DO content was higher than northwestern Kinkony Lake with values ranging from 2.89 to 5.38 mg/l (Rasoloariniaina, 2010). Spatial differences, the higher oxygen concentration in the center of the lake could be explained by the fact that the center zone is well aerated because such an area is connected to an open water body and the wind blowing creates turbulences and increases the exchange of atmospheric air with the water surface. Lower oxygen concentration during the rainy season could probably explain that the lake was more polluted during the flood season when the Anjombony and Ambavany Ankazobe rivers flowed into the lake and run-off from agricultural land could carry chemical pesticides and organic matter into the lake. During the wet-hot season, the decomposition of organic matter reduces the solubility of oxygen in the water while the temperature increases (Lowe-McConnel, 1987).

The overall trend in the evolution of pH levels and oxygen contents, less basic and lower oxygen during the rainy period and in the littoral zones corroborates the positive relationship between both parameters, resulting from the present study.

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Conclusion and recommendations

First knowledge of the characteristics of Lake Tseny is important because it provides a baseline and references data for lake Tseny wetland. The physical structure of the lake showed the spatial variation in habitat conditions favourable to sustain aquatic fauna. The sacred sites associated with prohibitions indicated the importance of traditional cultures in and around the lake. The physico-chemical parameters showed spatial and seasonal variations in water quality. Overall, the physico-chemical parameters indicated good water quality for domestic use and suitable conditions for the life of aquatic species, including fish. The observed variations could change to unfavorable conditions due to the increase in agricultural activities in the surrounding areas and forest degradation in the study area, as well as the impact of climate change on the water system. This needs to be taken into account to ensure the conservation of critical and indigenous species and the well-being of people. In the short and long term, regular monitoring of physico-chemical parameters should be carried out to detect any changes in the variability of the parameters and to decide on appropriate management measures. With regard to human health, the presence or absence of microbial contamination should be verified. Monitoring water quality through the structure of phytoplankton and macroinvertebrate communities, which are among the best biological indicators of water quality, should be put into practice. Further vertical studies at different times of the year are required to provide information on the water column. In terms of physical characteristics, the process of artificialisation of the lakeshore should be monitored to assess the rate of degradation of the rive.

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Data availability: All of the data are available in the content of the paper.

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