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Full Length Research Paper

Contribution to knowledge of the Lakes of Ounianga by bathymetry and physicochemistry

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This work aimed to contribute to knowledge improvement of the great Lake ecosystems of Chad, precisely that of the Lakes of Ounianga using bathymetric statements on water levels and the *in situ* analysis of physicochemical parameters of the lake's waters. Bathymetric surveys facilitated characterization of the morphology of the bottom of the lakes with depths that vary from 0 to -27 m and 0 to -5.7 m for Yoan and Teli Lakes, respectively. With regards to water physio-chemistry, the temperature of the Teli Lake water measuring up to 0.5 m varied from 20.8 to 36°C, while that of Lake Yoan varied from 10.50 to 32.90°C, with an average of 22 and 27°C. The conductivity values oscillated between 69 and 111,700 µS/cm for the Lake Teli and 100 to 64,000 µS/cm for the Lake Yoan. This document illustrates the techniques used in the investigation of a lake whose study constitutes a wide field of continental hydrology.

Key words: Ecosystem, lakes, bathymetry, physio-chemistry, Ounianga, Chad.

INTRODUCTION

Bathymetry is defined as measurement of the depth of a water body through survey and processing of the corresponding data in order to determine the configuration of its base. It is a factor which determines the operation and quality of the lake ecosystems (Demers and Arvisais, 2011; Ostendorp, 2004). Indeed, the morphological characteristics of the lakes determine the thermal mode of stratification and thus indirectly determine the circulation of water, the suspended matter

and the nutrients (Bragg et al., 2003; De Bortoli and Argillier, 2006). The variation in depth influences the availability of habitats while acting on the relative surface of the littoral zone and the availability of light for the process of stratification. Furthermore, it gives information on the distribution of sediments. More generally, bathymetry contributes to the apprehension of factors which determines the distribution of the aquatic communities: depths, pressures, temperatures, effects on

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the currents.

It is probably due to all these reasons that the French co-operation via its project Great Lake Ecosystems of Chad (GELT) aims at including/understanding the diversity of Chad ecosystem, which indeed contributes to the richness of the country. This system studies five Lakes, of which some are at the heart of the desert; as is the case with the Lakes of Ounianga. Although located in a tourist area, recognized as a United Nations Educational, Scientific and Cultural Organization (UNESCO) world heritage site, Ounianga Lakes were not the subject of systematic studies for many years. However, these Lakes are of a great scientific, tourist and economic interest together with their specificity of operation within the great Lakes ecosystems of Chad. Capot-Rey (1961) and Tubiana (1997) worked on the determination of the vegetation cover of Ounianga and Sérir Lakes. Kuper and Kröpelin (2006), Kröpelin (2007a, b), and Kröpelin et al. (2008) studied the sediments deposits of the Lake Yoan, which are of great interests in the reconstitution and evolution of the climatic and environmental conditions on a worldwide scale, while Burgis and Symoens (1987) described and gave brief overview of all the Lakes existing in the Sahara.

This paper is the first investigation of continental hydrology in the study zone which consists of 11,224 inhabitants on a surface of 62,408 ha with tourism, agriculture and breeding as principal economic activities (INSEED, 2012). It aims at contributing to the knowledge improvement of the great lake ecosystems of Chad, precisely that of Lakes of Ounianga, in order to better understand: (i) their structure, (ii) variation of the lakes depth, and (iii) physical properties of the lakes waters. Bathymetric measurements make it possible to partly answer the elements required in the last two points, which are the depth and lakes structure. Bathymetry is thus a criterion impossible to circumvent for description of morphology of the water levels by means of data collection during the Ounianga mission (project GELT). A bathymetric survey involves the use of bathymetric charts, consideration of current volume and use of hypsometric profiles to determine the bathymetric provinces. The *in situ* analysis of the physicochemical parameters will as a result include charts of space distribution of the temperature and conductivity according to the depth. This document shows the techniques of investigation in the case of a lake whose study constitutes a wide field of continental hydrology.

STUDY AREA AND METHODOLOGY

Localization, geological and climatic tallies

Located in the north-east of Chad, between Ennedi and Tibesti (Figure 1), the Lakes of Ounianga, which are a series of Lakes, ponds and marshes, are grouped into two sets known as: Ounianga Kebir and Ounianga Seghr/Serir. The distance between the two sets is about sixty kilometers by road (approximately 40 km on

space, between Lake Yoan and Lake Teli). The two groups of lakes, Ounianga Kebir and Ounianga Serir, consist of a total of eighteen lakes of which four are Ounianga Kebir and fourteen are Ounianga Serir. The first group of lakes (Figure 1B), Ounianga Kebir, consists of four lakes (Yoan, Uma, Mioji and Forodone) of which the principal lake, known as Yoan, extends on a surface from 358 ha (approximately 3.58 km²). The second group of lakes (Figure 1C), Ounianga Serir, consists of fourteen lakes (Ardjou, Abromé, Agouta, Bedrim, Boukou, Boul, Hogou, Edem, Melekoui, Dierké, Djara, Tarem, Teli, Tibitchei) separated by dunes. They are staged from 359 to 345 m of altitude, covering a surface of less than 10 km², within the center of the basin is the widest Lake Teli which is low and around 4.4 km². This present document is limited to the two principal lakes which are the Lakes Yoan and Teli.

The climate of this zone is hyper arid which is marked by long periods of dryness and the absence of a rainy season. Precipitations are always lower than 25 mm with sometimes several consecutive years without any precipitation. An extraordinary intensity of evaporation of 7,800 mm per annum, a very strong thermal amplitude (the difference in temperature between the hottest month (May) and the coldest month (January) which is higher than 30°C with extreme amplitudes reaching up to 47°C, are all characteristics of this zone (Capot-Rey, 1961). Lastly, most of the year, this region sometimes undergoes violent winds of north-eastern direction, which generates a displacement of barchans and various stranding. The various lake sets of Ounianga occupy the depressions of tectonic origin, dug and modelled by old river erosions and wind mills (Kröpelin, 2007b). Although they are no longer connected to a hydrographic network, these lakes still exist under this extreme climate thanks to the great number of sources, with diffused flow, which feed them along their banks. These sources correspond to resurgences of the fossil sheet of water of the vast aquifer of the continental interlayer. They ensure that water levels of the lakes are nearly constant, with fluctuations of approximately 0.5 m according to the seasons, while for the Lake Yoan, a maximum water level in March and April and a minimum in September and October is evident (Capot-Rey, 1961; Jungraithmayr et al., 1997). The whole of the Lakes Ounianga Sérir, located in a clay origin of broad depression 10 km, is of hydrological characteristics (Kröpelin, 2007b; UNESCO, 2011). With the exception of the Lake Teli, which is particularly dirty, all other surrounding lakes have fresh water or brackish (Van Bocxlaer et al., 2011), and are partly or completely covered with reeds (*Eragrostis bipinnata*). Finally, contrary to the water discharge system of the close lakes, the water of Lake Teli is particularly salted because of the intense evaporation to which it is subjected.

The geological make-up of the zone under study shows that majority of the formations belong to the Continental guide, also called Grès of Nubie (Hissene, 1986). The lakes are located in a monotonous formation of white likings similar to kaolin, which are finely light and strongly fractured, called Lake formation of which the thickness recognized by drilling is about 120 m for Lake Ounianga Kébir. The argillaceous sandstones and sandstones cover this series, which levels primarily in the depressed zones; this is the formation of Ounianga, recognizable from its pink color. The formation of the lakes and that of Ounianga are probably of Jurassic age (Wolff, 1964; Hissene, 1986).

The sandstones of Nubie contain a general aquifer drained on the one hand towards the North (zone of the palm plantations of Koufra) and on the other hand, towards the lowest altitude of Chad. The hydraulic load is such that it provides artesian water in the topographic depressions: Koufra and Faya. The water is naturally soft, are salted (the common facies is carbonated sodic) in the sectors where the surface of the tangent tablecloth surface of the ground, particularly in the low depth and deep water as detected in drillings undertaken at Faya-Largeau (4 drillings carried out in 1961 - 1962 between 155 and 350 m) and the surveys conducted with Ounianga.

Figure 1. Chart of Northern Africa exchange (A) with localization of the zone of Ounianga in the North-East of Chad located between the mountainous solid mass of Tibesti and Ennedi (Van Bocxlaer et al., 2011); the satellite image of the spot assembling (B) Ounianga Kebbir and (C) Serir.

Ground data

Surveys and bathymetric treatments of probes

The bathymetric data of the Lakes Yoen (Ounianga Kebir) and Teli (Ounianga to Serir) were collected via bathymetric surveys, carried

out using an electronic echo sensor of Garmin type, series 70, coupled with a system of localization by saTelite simultaneously (Global positioning system - GPS). The transducer (left transmitting the sonar) is fixed to the back of the boat such that it is constantly immersed in water. The bathymetric surveys were carried out by making turns or circle initially to the periphery (Figure 2) of the Lake

Figure 2. Localization of the points of measurements (way carried out).

and while evolving gradually to the center, the acquisition of the data is automatic on a step of regular time (each 10 s). This resolution was applied to the unit of the Lake. Thereafter, the bathymetric data were analyzed and transcribed with the aim of establishing the isobaths of depth of the water level. The depths obtained thus represent measurement between the position of the transducer of the echo sensor and the water-sediment interface. No correction of data was made in order to determine the real depth at each point, since the water of the lakes was not disturbed. However, despite all the precautions taken on the ground, the echo sensor does not measure depth lower than 0.6 m. To mitigate the null bathymetric data (0 m) which is perhaps also due to a boiling of the outboard motor and the bad alignment of probe etc, this vacuum was filled using the *in situ* inspections and a graduated pole of a value of 0.5 m and a value of zero was imposed for the contour of the Lake. More than 9,069 points for the Yoan Lakes and 7,049 points for Téli of echosondeur were thus collected. Each one of these points is composed of co-ordinates X (longitude), Y (latitude) and Z (altitude or depth in this case). The bathymetric chart was generated thanks to the Surfer modeling software of surface with the method of Krieger. This is based on techniques of geostatistics used to calculate the autocorrelation that enters points of measurement. The advantage of this method is that it takes into account the specific space behavior of the studied variable (Alleaume et al., 2010). Lastly, these data made it possible to calculate the surface of the zone, its relative importance (%), total volume (m^3), the maximum depth (Zmax), the average depth (Zavrg) and the Zavrg/Zmax report/ratio.

The physio-chemical measurement of the lakes water parameters

At the time of the inventory, the physicochemical parameters for water of the lakes were measured at a depth of 0.5 m using a continuous multiSonde WTW MPP-350. The data relating to the temperature and conductivity at the time of the bathymetric survey was synchronized with GPS Map Garmin. Thereafter, using probe

WTW, the pH, the temperature and conductivity were measured for the whole of the Lakes Ounianga Kebbir and Serir, as well as the surrounding sources.

RESULTS AND DISCUSSION

Bathymetry and morphometry

The detailed examination of the bathymetry of the Lake Yoan and Téli reveals a relatively complex basic morphology (Figure 3). The range of colors and the values of the isobaths highlight different provinces from the Lakes. For the Lake Yoan, three morphological types were identified: (a) the channel type (of direction -so) which meets in the zones of significant current sedimentation and corresponds to a depression located at the center of the lake with a maximum depth of 27.5 m. In this zone, the contribution of sedimentation is supposed to be significant; (b) the beach, whose slope is located in zones of current sedimentary contributions and (c) between these two bathymetric profiles is observed intermediate morphological types that presents significant changes of inclines corresponding to the *beach* - rock'n'rolls. As a whole, the depth decreases from the center towards the periphery of the lake. However, the highest depths (28 m) are observed mainly on level NNE of the lake and two other sections.

The Lake Téli, of rather lengthened form, which shows reliefs immersed in the form of hillock, testifies and presents five arms with small islands in the middle of the lake. The isobathic chart of the Lake Téli (Figure 3B) shows that the depths vary from 0 to 5.6 m. The lowest

Figure 3. Bathymetry of (A) Lake Yoan and (B) Teli. Source of Data : GELT-2016

Table 1. Morphometric characteristics of the Lake Yoan and Teli

Parameter	Lake Yoan	Lake Teli
Surface area (km ²)	3.58	4.4
Total volume in (m ³)	53822631.144	10262248.367
Z=0	m ³	m ³
Average depth (m)	11.70	2.74
Maximum depth (m)	27.51	5.55
relation Zavrg/Zm ax	0.42	0.49

depths are observed on the parts of lake where they reach 5.6 m and the maximum depth located at the East of the lake is 5.6 m (Figure 3).

From morphological point of view, the difference between these two lakes is well marked initially by the form of which the first is conical and the other is lengthened. The lake Yoan is much deeper than that of Teli whose depth varies from 0 to 5.6 m. The volume of water for the Lake Yoan is estimated as 53,822,631 m³ and for the Lake Teli as 10262248 m³ (Table 1 and Figures 4 and 5).

Physio-chemistry of the lake water

The various physicochemical parameters are also important when an evaluation of the quality of a water level is carried out in order to determine if it is favorable for a particular species. The water temperature influences

the quantity of energy available for the biological productivity and the chemical processes in the lakes, including the quantity of dissolved oxygen which is essential for the maintenance of the aquatic life (Environnement Canada, 2011). Moreover, the thermal structure of the water of a lake can be conferred with increase in ecosystemic diversity. Certain species prefer hot water of the surface layer of the lake such as millers and the mudfish (Demers and Arvisais, 2011) while others prefer deeper cold water such as the burbot and salmonides. The temperature of the water of the Lake Teli measuring up to 0.5 m varies from 20.8 to 36°C and for the Lake Yoan it varies from 16.50 to 32.9°C (Figure 6). Water conductivity is a measurement of the resistance of an aqueous solution to an electric flux (Wetzel, 2001). It is a good indicator of the abundance of ions in water. The measurements of conductivity taken at the time of the bathymetric survey only deal with surface lakes. The chart of space distribution of conductivity is not

Figure 4. Digital elevation model of (A) Lake Yoan and (B) Teli.

Figure 5. Digital elevation model of (A) Lake Yoan and (B) Teli.

Figure 6. Variations in temperature of surface water of the Lakes Yoan and Teli.

Table 2. Physicochemical parameters of the Lakes of Ounianga, October 2016.

Zone	Lake	Localisation		Conductivity ($\mu\text{S}/\text{CM}$)	Surface temperature ($^{\circ}\text{C}$)	O_2 (mg/l)	pH	Altitude (m)
		Latitude	Longitude					
O. Kebir	Yoan	19.802°N	20.5554°E	64000	26.36	9.84	9.92	
	Miodji	19.01097°N	20.51655°E	72000	22.1	7.37	10.10	373
	Uma	19.01143°N	20.51597°E	172000	24.3	4.32	9.72	373
	Forodone	19.0051°N	20.51597°E	12860	21.5	0.03	9.56	
	Teli	19.93333°N	20.86667°E	112100	25	3.80	9.74	
	Djabou	19.0051°N	20.5307°E	165600	30.9	6.06	9.79	365
O. Serir	Os bokou	18.91546°N	20.91156°E	326	23.3	6.43	7.77	356
	Bedrim	18.91711°N	20.90246°E	737	19.4	0.74	8.03	352
	Djara	18.91792°N	20.89266°E	1343	23.1	3.02	7.9	349
	Agouta	19.12202°N	20.88825°E	1807	23.6	6.23	8.33	422
	Hogou	18.92628°N	20.88106°E	1883	24.9	5.44	8.16	
	Ayou	18.92958°N	20.86019°E	2880	22.5	4.32	8.74	300
	Edem (Petit)	18.93094°N	20.85452°E	896	22.2	5.48	8.49	322
	Edem (Grand)	18.93029°N	20.85097°E	678	23.7	5.91	8.60	345
	Source							
	Source A1 (Ourouli)	19.10604°N	20.49286°E	344	31.2	2.52	6.98	
Lake Yoan	Source A2 (Ourouli)	19.10604°N	20.49286°E	403	31.2	2.19	6.88	
	Source B	19.05329°N	20.51059°E	223	26.4		7.34	414
	Source C	19.05994°N	20.49671°E	378	31.1	2.30	7.02	
	Source D	19.05909°N	20.49629°E	313	31	2.54	7.59	375
	Source E (Hoye)	19.06838°N	20.51174°E	340	31.6	1.77	7.03	370
	Source F (Mogie)	19.01015°N	20.51649°E	340	29.8	2.93	6.6	373
	Source G (Yaki)	19.05878°N	20.52065°E	215	24.1	2.44	7.59	373

represented here because of their homogeneity on the whole of surface of the lakes. However, the result of *in situ* analysis shows that the highest conductivity is that of the Lake Teli with 111700 $\mu\text{S}/\text{cm}$ followed by Lake UMA

and Yoan with values 172000 and 64,000 $\mu\text{S}/\text{cm}$, respectively. The pH varies from 6.6 to 10 and dissolved oxygen varies from 0.03 to 9.92. The results are consigned in Table 2.

Conclusion

This study on the Lakes of Ounianga (Kébbir and Serir) could highlight morphology of the bottom of the Lakes (Yoan and Teli) and the physicochemical characteristics of the lakes water. The data from the bathymetric lifting was increased for the Lake Yoan, with three morphological standards: (a) the channel type (of direction - so), which corresponds to a depression located at the center of the lake where the contribution of sedimentation is supposed to be significant; (b) the beach, whose slope is relatively constant, located in zones of current sedimentary contributions and (c) between these two bathymetric profiles, with observed intermediate morphological types which presents significant changes of incline corresponding to *the beach* - rock'n'rolls. The Lake Teli is of rather lengthened form, with a relatively low depth than that of the Lake Yoan. This Lake shows the presence of several islands immersed under water with stiff slopes.

The *in situ* analyses of the physico-chemical parameters of the lakes water and sources show that the Lake Teli is more salted with a conductivity of 112100 $\mu\text{S}/\text{Cm}$ followed by Lake Uma and Yoan, respectively with conductivities of 172000 and 64000 $\mu\text{S}/\text{Cm}$, respectively. The chart of space distribution of the temperature is less heterogeneous. The temperature of the water of the Lake Teli measuring up to 0.5 m varies from 20.8 with 36°C, while for the Lake Yoan, it varies from 10.50 to 32.90°C, with an average of 22.27°C. The water pH of the Lakes Yoan and Teli is basic which is similar to the surrounding lakes.

This study contributes to improvement of knowledge of the great Lake ecosystems of Chad, precisely the Lakes of Ounianga. Bathymetric measurements made it possible to answer the questions of structure and depth variation of the lakes. However, for a better interpretation these data must be associated with the sedimentological data.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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