Preliminary Analysis of Satellite and Field Data for the Determination of Water Quality in the Conservation Zone in Gabon: The Case of Lake Mandza

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ABSTRACT

Lake Mandza covers more than 4,000 ha and provides ecosystem services to an entire region located in the southwest of Gabon. In a context where in situ data are scarce, the aim of this work is to verify whether satellite data associated with those of transparency and surface temperatures can make it possible to detect a deterioration of the water quality of Lake Mandza. This study shows a spatio-temporal variation in water temperatures in Lake Mandza, which is characterized in particular by an increase of around 2 °C between 1987 and 2017. As for the analysis of the transparency data, it corroborates the hypothesis of a gradual deterioration of the water quality.

Keywords: Lake Mandza, Landsat images, Secchi disk transparency, surface temperature.

I. INTRODUCTION

Water is one of our most precious resources, one of the most abundant, but also one of the most inaccessible [1]. Indeed, if submerged land seems to represent about 71% of planet Earth, man can only use less than 1% of the total volume of the hydrosphere, or nearly 0.028%; the remaining 99% is either frozen or buried deep in the ground, and therefore cannot be easily mined for human consumption [2].

However, in the context of global climate change, we must not forget the inseparable link between climate and water. According to the IPCC, climate change affects the planet's water in complex ways, in particular through the disruption of rainfall patterns, the reduction of ice caps, the rise in sea level or the accentuation of flooding phenomena and episodes of drought [3].

Reference [4] asserts that climate change is dangerously affecting the supply of fresh water and mentions that over the past twenty years, the storage of terrestrial water, including soil moisture, snow, and ice, has been shrinking at a rate of 1cm per year, with major ramifications for water security. It should be added that alongside these changes, the increase in world population and human activities are also contributing to the ever-increasing deterioration of accessible water bodies [5]. As a result, it seems more than necessary to know them, to make an inventory of them, and, of course, to monitor them [6], [7].

However, according to [8], knowledge and management of water quality are major issues in several growing economic sectors such as tourism, aquaculture activities, fishing, etc. He adds that forecasting phytoplankton blooms, simulating the future of urban effluents or accidental pollution are some examples of current needs for effective protection of human health, the environment or economic activities.

The 1971 Ramsar Convention constitutes one of the legal frameworks for drawing up an inventory and monitoring the ecological quality of aquatic ecosystems. Indeed, the Ramsar Convention is an intergovernmental treaty whose mission is: “The conservation and wise use of wetlands through local, regional and national action and international cooperation, as a contribution to the achievement of sustainability in the world” [9]. In April 2022, it has 172 signatory states, including Gabon.

It should be noted that any rational use of wetlands, such as lakes, is subject to a good knowledge of how these environments work. This requires the prior acquisition of useful planning and management information, the rapid and continuous collection and supply of reliable data, and the historical data series establishment and updating.

However, sampling lake waters, whether to follow their evolution over time or to determine mixing processes, is a laborious approach from which it is difficult to derive synoptic data [10]. Satellite images are a new and important source of data, and the potential has not yet been fully defined [11]. In addition, inland water quality modeling using remote sensing has already demonstrated its ability to make accurate predictions [12]-[14].

In Gabon, the hydrological network is so dense that one could qualify the country as a huge wetland [15]. It also has nine Ramsar sites (wetlands of international importance), totaling 3,001,769 ha. Paradoxically, while wetlands are shrinking under the influence of man and the climate change consequences, there is no monitoring network for the quality...
or quantity of water in Gabon. Thus, despite current tools, such as high-resolution satellite imagery and conservation efforts, many lakes in the country remain unknown.

Reference [16] notes that in Gabon hydrological observations are guided by utilitarian purposes, especially knowledge of the hydroelectric potential of a country very well endowed with resources. Similarly, [17] specifies that in the mid-1970s, Gabon had around fifty hydrometric stations, which disappeared with the departure of ORSTOM, which was a French research organization. It is noted that the absence of a network of observations equitably distributed over the Gabonese territory leads to a lack of the characteristics of groundwater and surface water knowledge. This observation leads to finding simple ways to understand hydrological ecosystems, to then ensure their sustainable management” [1].

Based on the opportunities offered by remote sensing applied to hydrology, we analyze the evolution of surface water temperatures and the transparency of the Secchi disk (over 30 years), in order to detect possible pollution. The publication of this data constitutes a basis for the managers of the Ramsar site to plan its management and development.

II. MATERIAL AND METHODS

A. Location of the Study Area

Lake Mandza is located in south-western Gabon in the coastal region known as Ogooué-Maritime, where we find the outlet of Ogooué, the largest river in the country. Also, it shares with neighboring regions several conservation areas, such as the Moukalaba Doudou and Loango National Parks or the Ramsar Bas-Ogooué, small Loango and Setté-Cama sites.

The Setté-Cama site is in the middle of two major hydrological complexes: the Ndougou lagoon to the north and the Nyanga River to the south, into which the waters of the lake may occasionally flow (Fig. 1). With an area of 4221 ha, Lake Mandza extends over a length of 8 km and a width of 6 km. This exoreic lake, shallow in the dry season (1 meter on average), can reach 3 meters in the rainy season [14]-[18]. It is mainly fed by the Douébi river, which has its source in the Doudou-Mounts, 240 meters above sea level, and expels its water overflow by the Mbissi river.

Soils of this area are composed essentially of sands, clays, and laterite (ferralitic soils), linked to the presence of Proterozoic migmatites and granites essentially constituting the Doudou-Mounts range [19].

![Fig. 1. Location of Lake Mandza.](image1)

B. Methodology

The determination of the water quality is exclusively based on the analysis of the transparency parameters and the water surface temperatures (Fig. 2). These data result from both satellite images and field observations. Indeed, field observations are essential to validate the results from the analysis of the images. In situ sampling, as well as data analysis, was made possible by 42 defined points on the lake, from a mesh size of 0.7 km (Fig. 3).

The temperature and transparency data collected between 9 a.m. and 4 p.m. are the result of four field campaigns carried out between June and July 2017. These campaigns, calibrated in relation to the release of the 2017 image, required the use of a boat and a GPS (model 64, from the GARMIN® brand).

Transparency data were collected when the water was calm and the sky cleared. Each time they were taken from the shaded side of the boat, as recommended by the Lake Kit [20]. According to the World Wildlife Fund (WWF) procedure, the process consisted of measuring 3 times the disappearance and reappearance of the Secchi disk.

Surface temperatures were acquired by immersing the temperature probe 10 cm into the surface of the water. The device used was a Multi 3430 SET G with Oxygen Optical Probe FDO® 925-3. Finally, this field data was calibrated and/or compared with satellite data, in particular Landsat images.

![Fig. 2. Methodological flowchart.](image2)
1) Landsat imagery

Landsat imagery was acquired between 1987 and 2017 (Table I). The images are multi dates, for two reasons: the first is that cloud cover is globally important in Gabon [21]; the second reason is that if the visiting time of Landsat satellites is 16 days, it may not be obvious that we can have images (usable) on the same date, every year. The images chosen for the study were selected during the dry period of the study area that is to say between June and September [22]. These images, regarding their spatial and temporal resolution, are not the finest images for tracking on a relatively short time step. However, in Gabon, they remain unique free images with a good temporal resolution to carry out a diachronic study from 1972 (launch date of the first Landsat satellite).

2) Transparency

References [23], [24] have shown an adequate correlation between the Secchi disk transparency data and the Landsat data. Nevertheless, in-situ data should be collected as close as possible to the satellite’s date of passage. In rural areas, data can be taken up to ten days before or after Landsat [24].

The data processed in this work were taken at three and two days before the Landsat satellite transit. In the end, the depth of the Secchi disk taken into account is the average of the disappearance and reappearance of the disk for each station [13]. The Secchi disk transparency model was generated as follows:

- **Spatial filter**
  After applying a median filter (5x5) to eliminate coherent granularity noise, we performed a maximum likelihood binary (ground / water) classification. This classification allowed to generate a water mask to have only images of water.

- **Extraction of spectral signatures**
  Previously created water images have served as a support for determining SDT values. Reference [25] recommend not taking into account water surfaces influenced by vegetation, banks or the bottom of the lake. Stations that were sampled near the shore and those where the disk was visible throughout the water column were discriminated against. A total of 9 stations were removed for this phase.

  Then, from the isolated image of the lake, we digitized the regions of interest on the 33 remaining stations points. Nevertheless, the clouds present on a good part of the western zone of the image of 2017, allowed us only to digitize 20. Reference [12] determined that seven well-distributed soil control points were sufficient in small lakes and up to 1000 points in very large lakes. The digitization of the regions of interest enabled us to extract the reflectance values of the 20 digitized stations. These values have been exported in ASCII format, for subsequent analyses.

- **Regression analysis**
  We later used a multiple linear regression equation. The regression equation used in this study is developed by [24]. It is defined by the ratio B1 (blue band) / B3 (red band), with the blue band (B1) for the lake water clarity regression model. In our case, the ratio of mid-infrared and near-infrared bands has produced better reflectance’s to deduce the Secchi disk transparency. The final equation was as follows:

\[
\ln (SDT) = a (B5/B4) + b (B4) + c
\]

where \( \ln (SDT) \) is Secchi disk transparency converted to natural logarithm, a and b are the coefficients, c is the constant value, B5 is the NIR band and B4 is the PIR band.

3) Water temperature

Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM +) sensors record reflectance data and store this information as a digital number (DN) between 0 and 255. This can be converted to temperature in degrees Kelvin, then in degrees Celsius.

- **Conversion of digital accounts into radiance**
  Landsat images uploaded to the USGS website are provided with Metadata. Using the ENVI 5.1 software, the first step was to convert the DN into luminance value. This was possible using the Gain and Bias method. The formula for converting DN is:

\[
CV_{R1} = \text{Gain} \times \text{DN} + \text{Bias}
\]

where \( CV_{R1} \) is the radiation value of the cell, DN is the numerical account of the value of the cell; Gain is the gain value for a specific band; bias is the polarization value for a specific band.

The ENVI formula in Band Math looks like:

\[
0.05518 \times (B1) + 1.2378
\]

The gain value specific to the scene is 0, 05518 and that of shift is 1, 2378.

- **Conversion of radiance to temperature**
  Once the digital accounts for the thermal bands were converted to brightness values, we converted the radiation to


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**TABLE I: SATELLITE DATA**

<table>
<thead>
<tr>
<th>Type</th>
<th>ID</th>
<th>Path &amp; Row</th>
<th>Sensor</th>
<th>Date</th>
<th>Spatial resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land</td>
<td>LT05_L1GS_1 185062 TM 1987</td>
<td>5 1987072</td>
<td>211_01_T2</td>
<td>July 26</td>
<td>30 meters</td>
</tr>
<tr>
<td>Land</td>
<td>LE7185062200 185062 ETM 2004</td>
<td>7 6_20170</td>
<td>211_01_T2</td>
<td>July 16</td>
<td>30 meters</td>
</tr>
<tr>
<td>Land</td>
<td>LC8185062201 185062 ETM 2017</td>
<td>7 001LGN00</td>
<td>211_01_T2</td>
<td>July 04</td>
<td>30 meters</td>
</tr>
</tbody>
</table>
temperature without atmospheric correction [26]. The inversion of the Planck function was used to derive the temperature values. The atmospheric formula is the following:

\[
T = \frac{K2}{\ln\left(K1 \times CVR1\right) + 1}
\]

where \(T\) is the temperature (in degree Kelvin), \(CVR1\) is the radiation value from cell, \(\varepsilon\) is the emissivity, \(K1\) and \(K2\) are the coefficients determined.

- **Temperature conversion (from Kelvin to Celsius)**

The temperature in Kelvin is equal to the temperature in degrees Celsius, to which 273.15 is added. The conversion of temperatures was therefore deduced by:

\[
T°(c) = T°(K) - 273,15
\]

where \(T°(c)\) is temperature in Celsius degree, \(T°(K)\) is temperature in Kelvin degree and 273,15 equivalent values to 1 °C.

### III. RESULTS

#### A. Secchi Disk Transparency

1) **In situ transparency**

Fig. 4 shows that SDT measures decrease as one moves away from June. At the beginning and in the middle of the dry season (May-July), the winds are calmer, and the rains sporadic or light. These climatic conditions favour the establishment of clearer waters. There is an intensification of the winds as the rainy season approaches (August-September) which impacts the water quality, hence the presence of cloudy waters [27], [28]. For example, SDT values range from 0.24 to 1.11 meters in June compared to 0.27 and 0.94 meters in July. Note that the SDT values collected on July 02 were used not only to calibrate the Landsat image of July 04, 2017 but also to formulate the regression equation of the prediction model.

![Fig. 4. Average value of SDT per collection day.](image)

2) **Satellite transparency**

To predict SDT, the best reflectance values were deduced from the visible bands of the electromagnetic field. The red (0.63-0.69 μm) and green (0.53-0.61 μm) bands showed a good correlation between the satellite data and those that were measured on the lake. Indeed, the transparency prediction model is based on a coefficient of determination relatively large (\(r = 0.75\), with an error of 0.25 (Fig. 5). Finally, the regression equation used is as follows:

\[
SDT = 1.20215 \times (B3/B2) + (-0.00415 \times B2)
\]

Likewise, for each station, Fig. 5 shows correspondences between the data measured directly in the lake and their relationship to the red and green bands of the 2017 Landsat image. For the 20 variables sampled, the mean of the SDT is 0.86 m. Note that with an error of 0.24, the mean SDT can be considered representative of the data measured directly in the lake.

The use of SDT data from Lake Mandza for the years 1987, 2004 and 2017 makes it possible to carry out a spatio-temporal analysis of its transparency. However, this required the prior highlighting of a certain number of classes determined by the value of their transparency (Fig. 6).

![Fig. 5. Result of linear regression.](image)

![Fig. 6. Variation of transparency in the lake.](image)

Detailed analysis shows that in 1987, the predominant SDT value class was 0.85-0.86 m. We note that this class covers almost the entire lake, with the exception of the shores, and the northeast and northwest areas where the transparency varies around 0.83-0.84m. Overall, the water in the lake can be considered clear in 1987 when compared to that of 2004. Indeed, that year, the class 0.76-0.77 m represents almost the entire lake while the extremities of the western zone and...
certain southern sectors of the lake are characterized by a slightly weaker transparency (0.73-0.75 m).

We have observed that in 2017, the 0.79-0.8 m class takes into account most of the waters of Lake Mandza. However, the littoral zones and some spaces located in the center of the lake are marked by a slightly recessed transparency (0.74-0.75 m). On the other hand, the northeast area which corresponds to the class greater than or equal to 0.81m, has the most lit columns of water.

Between 1987 and 2017, the average SDT decreased by 0.06 meters over the whole of Lake Mandza. In the discussion section, we formulate some hypotheses that could explain this slight decrease in transparency over such a long period (1987-2017).

B. Water Surface Temperatures

1) Water surface temperatures taken in situ

Surface temperatures were measured during the 4 data collection campaigns, between 8:32 a.m. and 4:43 p.m. Analysis of the data collected shows that the mean surface temperatures of Lake Mandza water are between 24.5 °C and 25.7 °C.

Overall, the evolution of temperatures, between 8 a.m. and 16 h, has a unimodal regime, with a minimum at 8 h (t = 24.4 °C) and a maximum at 13 h (t = 25.9 °C). Temperatures increase from 8h to 11 h (Fig. 8), and then stabilize between 12 h and 14 h, before falling from 15 h. This is explained by the fact that the temperature of the water depends largely on the temperature of the air [29]. The heights of average lake surface temperatures are therefore relative to those of the atmosphere.

2) Satellite water surface temperatures

Landsat-type images are regularly taken around 8:30 a.m. GMT, above Lake Mandza. The values below indicate surface temperatures at 9:30 a.m. (local time). Between 1987 and 2017, they varied between 21.12 °C and 23.21 °C. This is an increase of 2.09 °C in 30 years. Note that the spatial distribution of lake temperatures in 1987 is characterized by an increase from west to east, but this gradient was reversed in 2017.

Fig. 8. Hourly evolution of surface temperatures, between 8 am and 4 pm.

Another fact marking the hottest temperature class widely spread in the lake in 1987, fell sharply in 2004 and now only concerns small areas located to the northeast and south of the lake. But in 2017, the warmer temperatures of Lake Mandza are located only to the northeast of it. For a lake with an area of 4221 ha, the most surprising is, among other aspects, the absence of a homogeneous distribution of its temperatures.

In addition, the analysis of liquid samples representative of the overall physicochemical quality of the water is an approach that makes it possible to take into account other indicators of the quality of the medium [30]. The results of laboratory analyses carried out according to the standards of the World Health Organization (WHO) and those of Gabon show that the waters of Lake Mandza are predominantly acid. According to national standards, these waters contain an excess of ions, in particular: phosphates, hydrocarbons, and iron. Although the distribution of problem ions appears to be uniform in the lake, iron values predominate in the northern and southern areas of the lake. Is it related to the geology of the lake catchment area?
Many countries in Atlantic Equatorial Africa find it extremely difficult to set up hydrometeorological networks [21]. For example, it is impossible to carry out a hydro-climatic study in Gabon, on two normal (60 years), because of important gaps and the existence of many sequences of observations too short to be taken into account in the various studies [17]-[22]. Addressing this shortcoming requires costly and time-consuming work, but the increasing use of satellite information can, at least in part, alleviate it [31].

With particular regard to limnometric studies, several authors [25]-[31], [32] emphasize the need to use field data to calibrate data from satellite images and assess the state of lakes and other water bodies. Thus, the global and complete analysis of the transparency of the water and the spatio-temporal variation of Lake Malawi was made on the basis of an estimate of the depth of the Secchi disk from satellite data [33]. Likewise, water temperature in lake systems is important for environmental impact assessment and fisheries management among others [34].

In this study, the Landsat 5 and 7 satellite images, combined with field data, provide essential information for the assessment of water quality and the management of the aquatic ecosystems of Lake Mandza (located in an area of Gabon devoid of any hydrometric observation in situ). In fact, the use of transparency and temperature parameters makes it possible to detect irregularities in the physico-chemical composition of the lake water. This approach shows that the waters of Lake Mandza are rather clear in the dry season and their establishment would be favored by the climatic conditions of this season which are characterized, in particular, by atmospheric stability and an absence of precipitation [22].

During the dry season (June-August), [25] showed that the record level of turbidity in the lake was reached in August. Similarly, a decrease in the transparency of the water in the lake is observed as the rainy season approaches. In fact, as one moves away from June, the SDT values decrease. These first results deserve to be reinforced by an analysis of the transparency of lake waters in the rainy seasons because atmospheric instability and runoff water which collect all kinds of waste can contribute to the degradation of the quality of the water.

According to the results of laboratory analyses, waters of Lake Mandza are mostly acidic, but also contain an excess of ions: phosphates, hydrocarbons, and iron. Although the distribution of problematic ions seems to be uniform in the lake, iron contents predominate in the northern and southern areas of the lake. These are also results that deserve to be refined by extending the approach to all seasons and by listing all the human activities likely to contribute to the pollution of the lake.

Spatial analysis of the transparency and temperatures of the lake shows that the distribution of these two parameters is not homogeneous over the entire lake, as if it had many sectors with different characteristics. This zonation may be related to water level fluctuation, as observed in Lake Chad due to inter-annual rainfall variations [35]. On the other hand, if it is admitted that the lakes can be considered as potential markers of climate change, the analysis of the temperature by satellite image shows that the water body of Lake Mandza tends to warm up. We note, in fact, an increase of about 2 °C in temperature between 1987 and 2017. This result confirms that of [36] who had already mentioned a difference of 2,2 °C.

This result is interesting because it is a rise in temperature that concerns the coolest season in the study area, in particular, and Gabon, in general. It would be desirable to extend the methodological approach of this work to all of the rainy seasons to better characterize the temperature evolution of Lake Mandza. The validation of these results should allow the implementation of a protocol aimed at monitoring the water quality of surface water in Gabon.

V. CONCLUSION

Our planet is being subjected to unprecedented climate change, with far-reaching social and ecological repercussions. Reference [37] states that below the waterline, aquatic ecosystems are being affected by multiple climate-related and anthropogenic factors, the combined effects of which are poorly understood. However, in lake regions, [38] have shown that water quality can be compromised when they are subject to increasing anthropogenic pressures. If the pollution...
of water bodies has become one of the most serious problems threatening aquatic ecosystems, as [30] has already pointed out, the difficulty is to measure the qualitative parameters illustrating these disturbances, especially in developing countries [39].

Overall, by the fluctuation of their volumes, the degradation of water quality, etc., the lakes present themselves today as sentinels of the spatio-temporal change of their environment, including changes related to climate change [40]. It is on the strength of this observation that the monitoring of the dynamic change of lakes has become one of the main subject of remote sensing applied to hydrology [41].

Besides, the emergence of new optical sensors offers a unique capability for comprehensive monitoring of aquatic environments and lakes in particular. The improvement in quality and increased access to satellite imagery time series data now constitute considerable scientific and technical progress in the environmental characterization of natural environments [11]. For example, [42] were able to define lake thermal regions using objective analysis of seasonal surface temperature dynamics from satellite observations. Similarly, the exploitation of satellite data has shown not only the quasi-stability of the extent of the waters of Lake Nzeng-Ayong but also the consequent degradation of the vegetation covered around this stagnant body of water located in the sixth district of Libreville in Gabon [43].

Due to its geographical location and its climatic conditions, Gabon is a country that has abundant surface water resources but whose quality is not controlled. This is partly explained by the absence of networks for measuring hydrological or environmental parameters [17]-[44]. To make matters worse, due to lack of a management plan, the Ramsar Label is not enough to strengthen the monitoring of freshwater ecosystems. However, it is a provision taken into account in the Ramsar Convention, of which Gabon is a signatory.

The SDT prediction model and the estimation of surface temperatures, produced in this work, made it possible to fill the lack of previous water quality data. This study shows that the distribution of surface temperatures of Lake Mandza is not homogeneous, with the northeast of the lake being the hottest zone. Similarly, between 1987 and 2017, the waters of Lake Mandza showed a trend of rising temperatures of about 2°C.

However, the period taken into account in this work concerns the dry season, the coolest in Gabon, hence the need to extend the research to all the climatic seasons of Lake Mandza. In addition, the analysis of the transparency dynamics of the waters of Lake Mandza shows that if these waters are clear in the dry season, they tend to become cloudy as one moves away from the dry season.

Finally, this study provides preliminary results that have a direct impact on improving our ability to analyze and monitor the quality of Gabon's aquatic ecosystems, particularly small water bodies. Specifically, the efficient evaluation of lake water quality requires not only the consideration of temperature and transparency parameters but also the integration of other physical variables such as the evolution of dissolved oxygen, precipitation intensity or vegetation cover. However, as with all remote sensing work, the effectiveness of this approach is dependent on the quantity and quality of the data provided in the field. Our future work envisions, in any case, proceeding to the modeling of several indicators whose combination could allow the extraction of a signal indicating a degradation of the lake ecosystems.

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**CONFLICT OF INTEREST**

Authors declare that they do not have any conflict of interest.

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