

Assessing the Temperature of the Mantasoa Lake Using Landsat8 Thermal Infrared Data

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Abstract Temperature is one of the key parameters to evaluate the water quality. This work aimed to present a methodology to determine the temperature of the Mantasoa Lake. The temperature of the Mantasoa Lake was estimated using images in the thermal infrared bands from Landsat8 after processing the atmospheric correction and calculating the brightness temperature. The results obtained demonstrated that the remote sensing technique provides an excellent relationship between the measured temperature values and the calculated ones. Moreover the correlation coefficient (R^2), which was equal to 0.955, was strong, and the root mean square error (RMSE) was 0.981. The temperature distribution maps indicates that the Mantasoa Lake respects the Malagasy norms on May 27, 2020 and May 30, 2021 regarding temperature.

Keywords Remote sensing, Landsat8, Surface water, Temperature, Lake Mantasoa

1. Introduction

Lakes are a vital component of Earth's fresh water resources, and are of fundamental importance for terrestrial life (Stuart MacCallum, 2012). The monitoring and assessing of the quality of lake water are very important for managing and improving its quality. The field observations, the collection of water samples and analyses in laboratory are currently methods to evaluate water quality. However, these methods are very expensive, time consuming and do not give either the spatial or temporal view of water quality needed for an accurate assessment of water bodies.

Remote sensing techniques provide spatial and temporal views of surface water quality parameters that are not available from the field measurements (Jerry C. et al, 2003) and they help sometimes to solve some problem linked to in-situ measurements (access, means). Water quality of a Lake is determined by physicochemical parameters such as turbidity, pH, salinity, dissolved oxygen etc. Temperature is a physical parameter that has an influence on the functioning of fresh water ecosystems (Najwa Sharaf et al., 2019). The purpose of this work was to use thermal infrared remote sensing to monitor the spatial distribution of the temperature of the Mantasoa Lake. Lake Mantasoa is a tourist site and also known has the Africa's first caviar farm. Water temperature plays an important role in sturgeon culture.

In this study, data images from the Landsat8 satellite were used. These images can be freely downloaded from the USGS (United State Geological survey) website. Landsat8 carries two sensors: OLI (Operational Land Imager) with nine spectral bands and TIRS (Thermal Infrared Sensor) with two spectral bands. The temperature of Lake Mantasoa was calculated using TIRS data images after calculating the emissivity and brightness temperature. To validate the formula of the lake surface temperature based on thermal infrared data, in-situ measurements were performed.

2. Study Area and Data Used

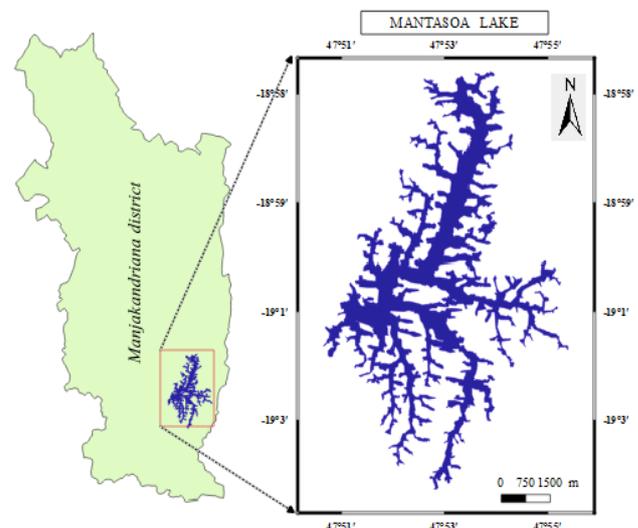


Figure 1. Location of the study area

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2.1. Study Area

The Mantasoa Lake is located in the Analamanga region, Manjakandriana district, rural commune of Mantasoa, about 56 km east of Antananarivo as the crow flies. Geographically located between 19°1' latitude South and 47°52' longitude East (Figure 1), it is an artificial lake created in 1936 to regulate the Ikopa river, to irrigate the rice-growing plain of Betsimitatatra and to supply the hydroelectric station of Mandraka (Randrianiaina Jerry J.C.F., 2021).

2.2. Data Used

Landsat8 data image products (path: 159, row: 073) were used in this work. The Landsat-8/ LDCM (Landsat Data Continuity Mission) satellite was launched in February 2013 to ensure the mission continuity of Landsat data at a high spatial resolution. Landsat8 carries two sensors on board: OLI (Operational Land Imager) and TIRS (Thermal Infrared Sensors). OLI has nine spectral bands with a 30 m spatial resolution for the eight bands, and one panchromatic band at 15 m. TIRS have a 100 m spatial resolution using two bands between 10-12 μm . The characteristics of Landsat 8 OLI/TIRS data imagery are given in Table 1.

Table 1. Landsat8 characteristics (Landsat 8 Data Users Handbook, 2015)

Band designations	Wavelength (μm)	Spatial resolution (m)
Band 1 (Coastal Aerosol)	0.43 – 0.45	30
Band 2 (Blue)	0.45 – 0.51	30
Band 3 (Green)	0.53 – 0.59	30
Band 4 (Red)	0.64 – 0.67	30
Band 5 (Infrared)	0.85 – 0.88	30
Band 6 (Short wave infrared)	1.57 – 1.65	30
Band 7 (Short wave infrared)	2.11 – 2.29	30
Band 8 (Panchromatic)	0.50 – 0.68	15
Band 9 (Cirrus)	1.36 – 1.39	30
Band 10 (Thermal infrared)	10.6 – 11.19	100
Band 11 (Thermal infrared)	11.50 – 12.51	100

3. Methodology

3.1. DOS1 Atmospheric Correction

The electromagnetic signals that the satellite or a sensor records are disturbed by particles suspended in the atmosphere (gases and aerosols). Atmospheric correction is necessary to subtract the diffusion and absorption phenomena in the atmosphere and to convert digital number (DN) to reflectance. In this study, DOS1 (Dark Object Subtraction 1) atmospheric correction was used to reduce the atmospheric perturbations. DOS1 is well accepted by the geospatial community (Song C. et al., 2001) and its surface reflectance is given by:

$$\rho = \frac{\pi * d^2 [L_\lambda - L_p]}{ESUN_\lambda * \cos(\theta_s)} \quad (1)$$

where L_p is the path radiance and L_λ is the spectral radiance at the sensor's aperture given by Equation (2).

$$L_\lambda = M_L * Q_{cal} + A_\rho \quad (2)$$

where M_L is the band specific multiplicative rescaling factor from metadata, Q_{cal} is the quantized and calibrated standard product pixel values (DN), and A_ρ is the band-specific additive rescaling factor from metadata.

3.2. Emissivity

The emissivity is an important parameter necessary to calculate surface temperature using remote sensing techniques. It is calculated using the equation (3) (Sorbino et al., 2008).

$$\varepsilon = 0.004 * \left(\frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \right)^2 + 0.986 \quad (3)$$

with

$$NDVI = \frac{NIR - R}{NIR + R} \quad (4)$$

where:

NIR and R are the Near Infrared and Red bands respectively,

$NDVI_{min}$ and $NDVI_{max}$ are the minimum and maximum values of $NDVI$.

3.3. Surface Temperature

To extract surface temperature by remote sensing techniques, thermal infrared remote sensing was applied, i.e. the method uses thermal infrared data. It is the only approach possible to extract surface temperature using remote sensing (Coll et al., 2007). The utilization of thermal infrared data allowed to give a direct measurement of the surface temperature (soil surface, water surface, etc.).

The definition of brightness temperature was used to derive the relationship between brightness temperature and kinetic temperature. The brightness temperature is the temperature required for a black body to emit energy at the same rate as seen in a gray body (David, A.A. and Walter H. C., 1982). Thus, the radiance for a black body $L_1(T_B, \lambda)$ at a brightness T_B is given by the relation (5)

$$L_1(T_B, \lambda) = \frac{\beta}{\lambda^5 \left[\exp\left(\frac{\alpha}{\lambda T_B}\right) - 1 \right]} \quad (5)$$

where: $\alpha = 1.438 * 10^{-2} mK$ and $\beta = 1.19 * 10^{-16} Wm^2$ are constants (David, A.A. and Walter H. C., 1982).

The radiance for a gray body at a temperature T , $L_2(T, \lambda)$ is indicated by the equation (6)

$$L_2(T, \lambda) = \frac{\varepsilon\beta}{\lambda^5 \left[\exp\left(\frac{\alpha}{\lambda T}\right) - 1 \right]} \quad (6)$$

By identifying the equation (5) to the equation (6) and neglecting 1 before the exponential term, the equation (7) was obtained. Previous research used the single channel TIRS data from Landsat8 to estimate surface temperature. In this study the water surface temperature was estimated by the two Landsat8 TIRS channels (Randrianiaina Jerry J.C.F et al., 2018).

$$T(^{\circ}C) = \left[\frac{\overline{T_B}}{1 + \frac{\overline{T_B}}{\rho} * \lambda * \ln(\varepsilon)} \right] - 273.15 \quad (7)$$

where: $\rho = \frac{hC}{\sigma} = 14388.15 \mu\text{m.K}$,

- h : Planck's constant ($6.626 * 10^{-34}$ J.s),
- σ : Boltzmann's constant ($1.38 * 10^{-23}$ J.K⁻¹),
- C : velocity of light ($2.998 * 10^8$ m.s⁻¹),
- $\lambda = 11.197 \mu\text{m}$,
- ε : emissivity,

$$\overline{T_B} = \frac{T_{B,i} + T_{B,j}}{2} : \text{mean of brightness temperature with}$$

$T_{B,i}$ and $T_{B,j}$ being the brightness temperatures obtained from bands 10 and 11 using the equation (8):

$$T_B = \frac{K_2}{\ln\left(\frac{K_1}{L_\lambda} + 1\right)} \quad (8)$$

with

K_1 and K_2 : Thermal conversion constant given by table 2

$$L_\lambda = M_\lambda * Q_{cal} + A_\lambda \quad (9)$$

L_λ : Top of atmospheric radiance,

Q_{cal} : Digital number,

M_λ : Band specific multiplicative rescaling factor from Landsat8 metadata,

A_λ : Band specific additive rescaling factor from Landsat8 metadata,

Table 2. Thermal constant

Thermal constant	Band 10	Band 11
K_1	774.8853	480.8883
K_2	1321.0789	1201.1442

4. Results and Discussion

The results obtained using this approach are shown in Figure 2 and Figure 3, which indicate the spatial distribution of the surface water temperature of the Mantasoa Lake. These figures show that the Mantasoa Lake temperature ranged from 17.4°C to 19.6°C on May 27, 2020 and 24.1 to 27.4 on May 30, 2021. It is indicated that the Mantasoa Lake respects the Malagasy norms because these are below 30°C. We mention that higher surface water temperature is in the peripheral of the lake which is shallow. It is noticed the Malagasy decree n° 2003/464 issued on April 15, 2003 concerning water surface classification stipulates that if the temperature is inferior to 25°C the lake water temperature is in a good quality category and in a class of medium quality in the case where temperature value ranges from 25°C to 30°C.

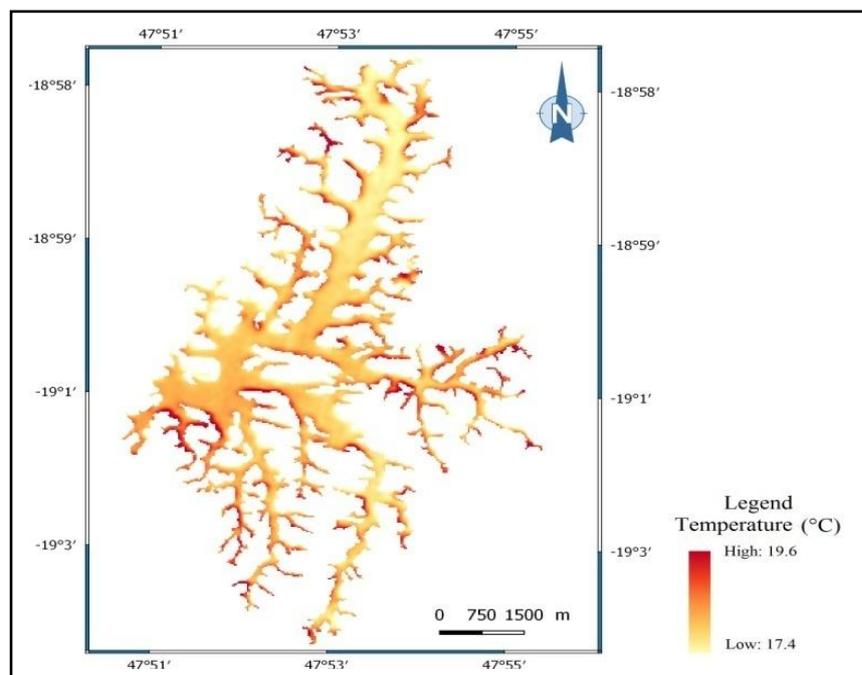


Figure 2. Map temperature distribution of Lake Mantasoa (27/05/2020)

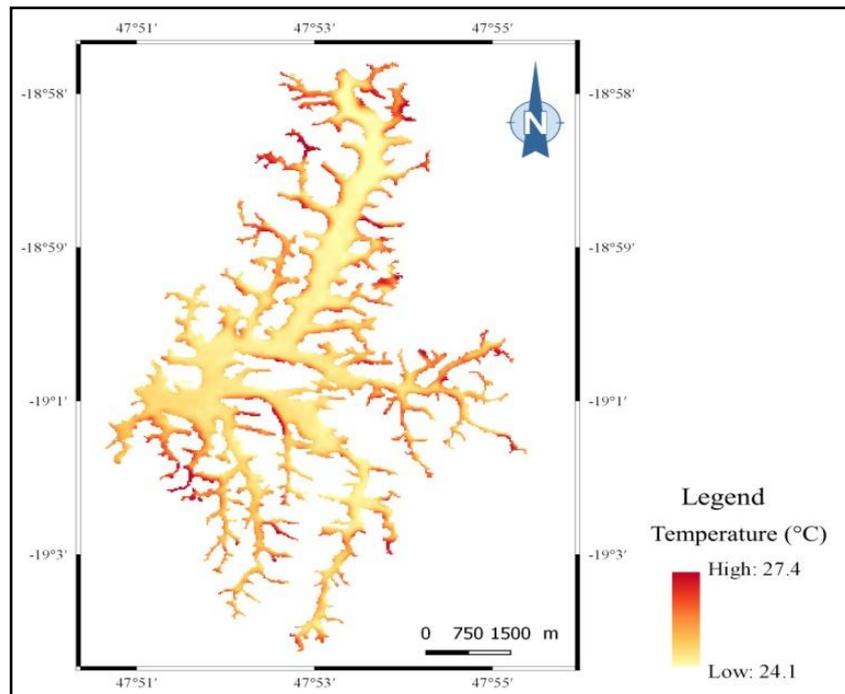


Figure 3. Map temperature distribution of Lake Mantasoa (30/05/2021)

The curves in the following Figure 4 show the temperatures measured in situ and the calculated temperatures; a series of 16 measurements were undertaken in this work. This figure shows that there is indeed a concordance between the measured and calculated values. The correlation obtained is strong, equal to 0.955, and the value of the root mean square error is equal to 0.981.

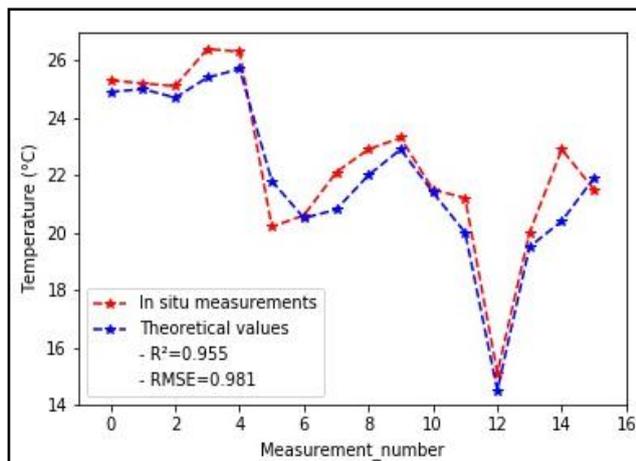


Figure 4. In-situ values compared with calculated temperature values

5. Conclusions

Lake water is vital for human and aquatic animals. A knowledge of water quality in regular time is necessary to protect this resource. Therefore, the Mantasoa Lake respects the Malagasy norms on May 27, 2020 and May 30, 2021 regarding temperature. The methodology adopted in this work gives a good concordance between the observed and

calculated temperature values of the water surface. In further work, in-depth measurements will be carried out to get a three-dimensional distribution of the lake water temperature.

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