

Remote Sensing Based Assessment of the Water Quality in Nador Lagoon, Morocco

Miroslav Ivanov¹, Emilia Varadinova², Veselina Dalgacheva³, Ouiam El Mekki⁴,
Konstantin Tyufekchiev⁵, Vladimir Karadzhov⁶

^{1,2,3,5,6} Department of Geography, Ecology, and Environmental Protection, Faculty of Mathematics and Natural Sciences, South-West University "Neofit Rilski" – Blagoevgrad

⁴ Laboratoire de la Lagune Marchica de Nador pour les Sciences Bio-Géo Physique et Environnement (LOLMAN-BGPE), Faculté Pluridisciplinaire de Nador, Université Mohamed Premier, Maroco

ORCID IDs: ¹ 0000-0002-2347-8029, ² 0000-0002-2382-9191, ³ 0000-0002-1976-5367, ⁴ 0009-0003-0225-4338, ⁵ 0000-0003-4473-9731, ⁶ 0000-0002-7514-5517

Corresponding Author: Miroslav Ivanov, m_ivanov@swu.bg

<https://doi.org/10.63711/ijdr.net20250407>

ABSTRACT

The main objective of this article is to compare remote sensing data with in situ measurements in order to assess whether Sentinel-2 satellite imagery and the Case-2 Regional Coast Colour (C2RCC) MSI processor can be used as a reliable tool for the ecological status assessment of stagnant water bodies as an alternative to traditional monitoring methods. The area of interest in this study is the Nador Lagoon, which is the largest lagoon within Moroccan territory and the second largest in North Africa after the El Bidan Lagoon in Tunisia. The lagoon has an oval shape, with a maximum length of approximately 25 km, an area of about 115 km², and a maximum depth of 8 m. Chlorophyll-a concentration was selected as a key indicator for assessing the trophic status of the lagoon. In situ measurements were conducted at 18 locations across the Nador Lagoon on 22.02.2023, 09.05.2023, 09.08.2023, and 22.12.2023. The satellite data used in this study consist of three Sentinel-2 images acquired on 22.02.2023, 05.05.2023, and 03.08.2023. Due to the 4-day revisit cycle of the Sentinel-2 satellites, the time difference between in situ sampling and satellite image acquisition was up to four days. The Sentinel Application Platform (SNAP, version 9.0) and the Case-2 Regional Coast Colour (C2RCC) MSI processor were applied to derive chlorophyll-a concentrations. Additionally, C2X neural networks were used due to the high turbidity of the lagoon waters. The comparison between in situ measurements and satellite-derived data shows a good correlation in chlorophyll-a concentrations, demonstrating that satellite-based monitoring is a fast and promising approach for ecological assessment. The results indicate that remote sensing techniques can serve as a cost-effective and efficient alternative to traditional water quality monitoring methods, particularly for large and dynamic aquatic systems.

Keywords: Satellite imagery, Chlorophyll-a, Ecological monitoring, Remote sensing.

INTRODUCTION

The Nador lagoon system, located in the northeastern region of Morocco, stands as the most significant regional paralic hydrosystem situated between the Mediterranean Sea and the African continent. Because of its importance, this lagoon is included in the list of the five Sites of Biological and Ecological Interest (SIBE), and it has been protected under the international Ramsar Convention since 2005 (Quaranta et al., 2021). The area of the lagoon represents a remarkable array of habitats, including marshy areas, dunes, and shallow waters, of significant importance to numerous flora and fauna species.

Among these species, the most predominant is the marbled goby (*Pomatoschistus marmoratus*, Risso, 1810). Furthermore, this locality holds significant importance as a wintering and resting site for more than 150 bird species (Dakki, 2003). Through its remarkable natural setting, the Nador Lagoon stands as a valuable asset for the development of other revenue-generating activities, such as ecotourism and various recreational activities (El Madani Farid, 2012).

The ecological status of the lagoon has been affected by numerous human activities, including urbanization, agriculture, fishing, aquaculture, tourism, and leisure. The pressures from these practices, coupled with uncontrolled discharges of wastewater, nutrients, organic matter, and heavy metals, negatively affect the delicate ecological balance of the lagoon. These negative factors are responsible for the widespread degradation of the lagoon ecosystem (Najih et al., 2017).

To protect the lagoon ecosystem and preserve the biological and ecological qualities of the water, as well as to promote the development of tourist activities in the area, two water treatment facilities – the Grand Nador and Arekmane purification stations – were built after 2010. Furthermore, a new channel between the lagoon and the Mediterranean Sea was opened to enhance water exchange between the two water bodies.

The undertaken measures have led to a noticeable improvement in the status of the lagoon, transitioning it from a “suffocated lagoon” to an “anemic lagoon” (Hilmi et al., 2015).

Currently, the water quality of the lagoon is subject to monitoring, and several biological and physico-chemical quality parameters are measured *in situ* three times per year. However, small, shallow, polymictic water bodies are largely affected by weather and climate dynamics, which can lead to strong fluctuations in their state.

Achieving reliable results for the environmental conditions in such lakes requires high-frequency monitoring, which is a time- and cost-consuming task. On the other hand, various parameters such as turbidity, chlorophyll-a concentration, and other indicators considered fundamental for water quality assessment can be derived from satellite images. The use of remote sensing techniques represents a valuable tool for mapping, detecting, monitoring, and assessing changes occurring within aquatic ecosystems while taking into consideration different temporal and spatial scales (Graetz, 1990).

The purpose of this research is to use freely available data from Sentinel-2 missions and to analyze these data using the Sentinel Application Platform (SNAP) and its incorporated optical water processors, which can generate information on optically determined water quality parameters, including chlorophyll-a and total suspended matter, and to compare these data with *in situ* measurements in the Nador Lagoon.

Over the past few decades, numerous studies related to water quality have been conducted using remote sensing technology, and they have demonstrated a good relationship between *in situ* measurements and water quality parameters derived from remote sensing data. For example, Toming et

al. (2016), Ansper et al. (2018), and Kazakov et al. (2020) reported a strong relationship between in situ data and Sentinel MSI data along a trophic state gradient.

STUDY AREA

The area of interest is the Nador Lagoon (Fig. 1), which is known by various names, such as Sebkha de Bou Areg or Marchica (the “small sea”), and stands as the most imposing lagoon expanse within Moroccan territory and the second largest in North Africa after the El Bidan Lagoon in Tunisia. This geographical feature stretches along the western coast of the Mediterranean Sea and is situated between Cap des Trois Fourches and Kariat Arekman (35° 09' 36" N, 2° 50' 24" E). It is an oval-shaped lagoon with a maximum length of up to 25 km.

The lagoon encloses an area of approximately 115 km², and its depth fluctuates between 5 and 8 m in the central part, gradually diminishing towards the shores.

A 25-kilometre-long sand bar separates Marchica from the Mediterranean Sea. This barrier incorporates an artificially built inlet, 300 m wide and 6 m deep. This artificial channel reduces the water renewal interval of the lagoon to approximately 15 days, which is a significant improvement compared to the 57-day water circulation cycle associated with the previous natural channel (Maicu et al., 2021).

According to data from the National Meteorological Directorate (Morocco Meteo), the average air temperatures observed in the area of the Marchica Lagoon range between 8 °C and 30 °C. The average minimum air temperatures generally fall around 8 °C during the winter and autumn seasons, increasing to approximately 10 °C–20 °C during the spring and summer periods.

The average relative humidity is 71.25%, indicating a relatively high level of humidity typical for the region. October is the wettest month, with a monthly average humidity of up to 74.6%, while August is the least humid month, with relative humidity of approximately 69% (Jouamaa et al., 2022).

The salinity of the lagoon ranges between 33 and 40‰, and because mixing of the water column is limited, a well-developed stratification of the lagoon water is observed. The annual precipitation rate is around 300 mm, while the prevailing winds originate from the west-northwest and the east, roughly aligning with the lagoon's primary axis (Maanan et al., 2015).

The hydrological equilibrium of the lagoon is defined by three main sources: (a) marine waters entering the lagoon through the artificial channel, (b) freshwater inflow originating from two extensive groundwater reservoirs, namely Gareb, located south of the Selouane River, and Bou Areg, situated near the southern margin of the lagoon, and (c) surface waters from ten small streams, commonly referred to as “oueds” (Jeyar et al., 2015).

Among these, the Selouane River stands out as the most significant tributary flowing into the lagoon and is also one of the main sources of pollution, due to the large amounts of municipal and industrial wastewater discharged into the river as it passes through the village of Selouane (Maanan et al., 2015; Ruiz et al., 2006).

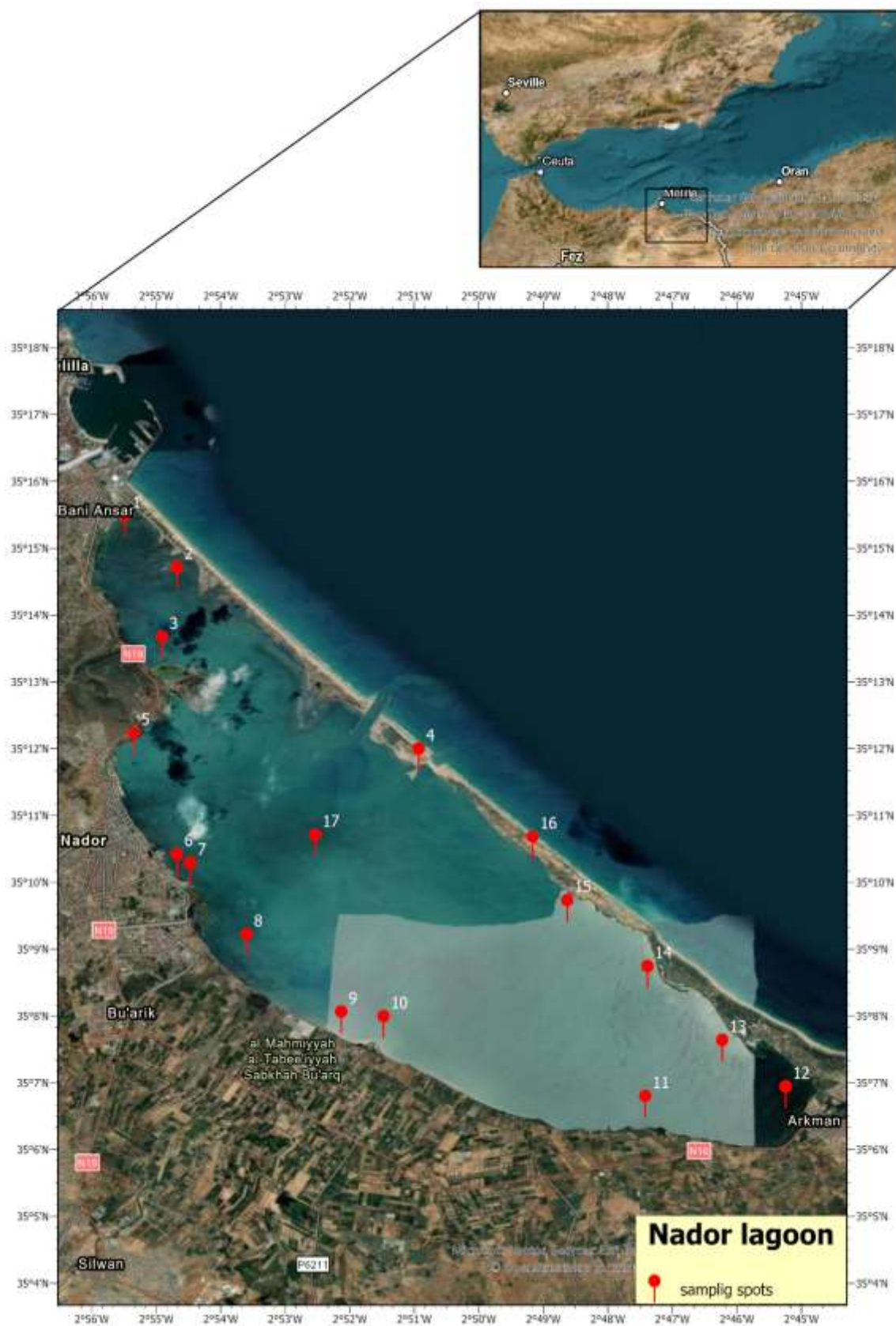


Fig. 1. Study area - Nador lagoon and the sampling spots.

MATERIALS AND METHODS

Field measurements at 18 locations (Table 1) along the Nador Lagoon were conducted four times in 2023 – on 22.02.2023, 09.05.2023, 03.08.2023, and 22.12.2023.

The samples were collected at 0.5 m below the surface, and water quality parameters such as dissolved oxygen, saturation, chlorophyll-a, turbidity, salinity, pH, and surface water temperature were measured. Chlorophyll-a concentration was determined spectrophotometrically after extraction in 96% ethanol.

Among the measured water quality parameters, water transparency, chlorophyll-a, and phosphorus concentration are the most commonly used indicators in the trophic status assessment of inland waters (Kazakov et al., 1997; Carlson et al., 1997). With recent advances in remote sensing techniques based on freely available satellite data from the Copernicus programme, some of these parameters, such as chlorophyll-a, turbidity, and total suspended matter (TSM), can be measured remotely.

In this research, freely available data from Sentinel-2 missions and the Sentinel Application Platform (SNAP), with its incorporated optical water processors, are used to generate data on chlorophyll-a concentrations within the lagoon and to compare these data with in situ measurements in the Nador Lagoon. The chlorophyll-a concentrations retrieved from satellite data and in situ measurements are presented in Table 1.

Table 1. Chlorophyll-a concentrations (mg/L) retrieved from satellite data and in situ measurements at 16 sampling spots (S.SP.).

S.SP.	In-situ data – 02.08.2023 Mg/l	Sat. Data- 03.08.2023 Mg/l	Diff.	In- situ data 05.05 Mg/l	Sat. Data- 09.05.2023 Mg/l	Diff.	In- situ data Mg/l	Sat. data - 22.02.2023 Mg/l	Diff.
2	5.02	3.94	1.08	3.19	2.85	0.34	2.46	6.05	-3.59
3	5.3	3.67	1.63	3.8	0.32	3.48	3.85	8.9	-5.05
4	6.52	8.82	-2.3	3.89	21	-17.11	2.81	2.9	-0.09
5	7.67	10.41	-2.74	2.28	2.36	-0.08	5.6	7.51	-1.91
6	6.92	13.16	-6.24	0	13.88	-13.88	7.35	14.02	-6.67
7	13.93	57	-43.07	9.75	9.6	0.15	3.57	11.53	-7.96

8	64.16	19.58	44.58	13.61	2.88	10.73	3.22	3.22	0
9	80.29	83.41	-3.12	33.9	23.06	10.84	4.65	6.32	-1.67
10	74.04	30.32	43.72	5.18	8.27	-3.09	5.6	10.27	-4.67
11	23.57	19.74	3.83	6.52	2.11	4.41	12.4	17.79	-5.39
12	4.86	20.65	-15.79	3.43	12.13	-8.7	5.5	34	-28.5
13	9	15.12	-6.12	2.77	4.98	-2.21	12.5	9.95	2.55
14	5.37	4.2	1.17	3.44	3.98	-0.54	5.23	4.45	0.78
15	8.69	14.37	-5.68	3.18	1.81	1.37	2.23	2.04	0.19
16	5.49	29.94	-24.45	0.91	12.97	-12.06	2.18	13.58	-11.4
17	3.48	2.26	1.22	2.57	1.69	0.88	4.2	1.13	3.07

Available satellite data from the Copernicus programme were used to determine chlorophyll-a concentrations. This parameter is important because it can be used to evaluate the trophic state of the lagoon. MSI Level-1C products extracted from satellite images captured by Sentinel-2 on 05.05.2023, 02.08.2023, and 22.02.2023 were downloaded from the Sentinel Browser and used for the analyses. Unfortunately, due to extensive cloud cover over the lagoon area in December 2023, it was not possible to identify a suitable satellite image matching the date of the December sampling campaign. Therefore, in this study, only data acquired *in situ* on 22.02.2023, 09.05.2023, and 03.08.2023 were evaluated.

Due to the four-day revisit cycle of Sentinel-2, the time difference between *in situ* sampling and satellite image acquisition was up to four days. The Sentinel Application Platform (SNAP, version 9.0) and the Case-2 Regional Coast Colour (C2RCC) MSI operator were used for the determination of chlorophyll-a concentrations, and due to the high turbidity of the lagoon waters, C2X neural networks were also applied. As Sentinel-2 Level-1C products incorporate spectral bands with different spatial resolutions, the products were resampled to a 20 m pixel resolution prior to image processing.

Sentinel-2 Level-1C products are not atmospherically corrected; however, atmospheric correction is automatically performed within the C2RCC processor. The required *in situ* environmental parameters for the operator, such as surface water temperature, salinity, and altitude, were also preset in the C2RCC processor. Recent studies have reported a good relationship between *in situ* measurements and Sentinel MSI data for chlorophyll-a concentrations (Kazakov et al., 2020; Toming et al., 2016; Ansper et al., 2018), although atmospheric conditions and hydromorphological features of water bodies can significantly affect the accuracy of the results (Coluzzi et al., 2018).

Kazakov et al. (2020), based on their research in Lake Srebarna (Bulgaria) and the Malak Preslavets swamp, proposed a methodological approach in which the *in situ* measured coordinates of sampling locations were used for pixel match-up selection from Sentinel images, where 3×3 pixel windows were extracted for each sampling station and average values were calculated.

In the study by Kazakov et al. (2020), all sampling spots were situated in the central parts of the investigated water bodies; however, in the Nador Lagoon, the majority of sampling locations are situated along the coastline, close to the shore. Because of this, if the pixel corresponding to a sampling point is grouped with neighbouring pixels and average values are calculated, taking into consideration the pixel size and the proximity of the shoreline, there is a risk that the averaged values will represent both pixels located within the lagoon water body and pixels situated on land beyond the lagoon's coastline, which would compromise the reliability of the results.

Taking into consideration the above-mentioned factors, in this study the chlorophyll-a concentrations in the pixels corresponding directly to the sampling locations were used for further correlation analysis. In this analysis, the *in situ* and satellite-derived data were compared to assess the reliability of chlorophyll-a information for the lagoon obtained using the Case-2 Regional Coast Colour (C2RCC) MSI processor.

RESULTS AND DISCUSSION

The analysis of the *in situ* measurements shows that surface water temperature ranged between 22.3 °C and 28.03 °C in spring (09.05.2023), between 27.1 °C and 30.08 °C in summer (03.08.2023), and between 14.5 °C and 16.2 °C in winter (22.02.2023). Dissolved oxygen concentrations varied between 5.17 mg/L and 12.12 mg/L in spring, between 3.39 mg/L and 11.20 mg/L in summer, and between 7.09 mg/L and 9.76 mg/L in winter. The spatial distribution of chlorophyll-a concentrations across the sampling locations indicates relatively low values during winter, ranging between 2.63 mg/L and 8.08 mg/L. Subsequently, values increased during spring, ranging between 0.91 mg/L and 33 mg/L, with chlorophyll-a concentrations reaching maximum values of up to 80 mg/L during summer. The remaining physico-chemical parameters exhibited similar seasonal dynamics throughout the year (Table 1).

The results from the satellite data analysis also confirmed a seasonal trend in chlorophyll-a concentrations, with increasing values from winter (22.02.2023) to summer (03.08.2023). The lowest chlorophyll-a concentrations were recorded during the winter sampling campaign, with values ranging between 1.13 mg/L and 7.79 mg/L across the different sampling locations. These were followed by increased upper values during spring, reaching up to 23.06 mg/L, while the maximum chlorophyll-a concentrations were observed during the summer sampling period, reaching up to 83.41 mg/L (Table 1).

Both satellite-derived and *in situ* data indicate a heterogeneous state and a complex spatial distribution of chlorophyll-a concentrations within the Nador Lagoon. Using both sampling approaches, higher chlorophyll-a values were detected in the shallow nearshore areas, close to urban or agricultural zones, whereas lower concentrations were observed in the deeper central parts of the lagoon (Figs. 2–4).

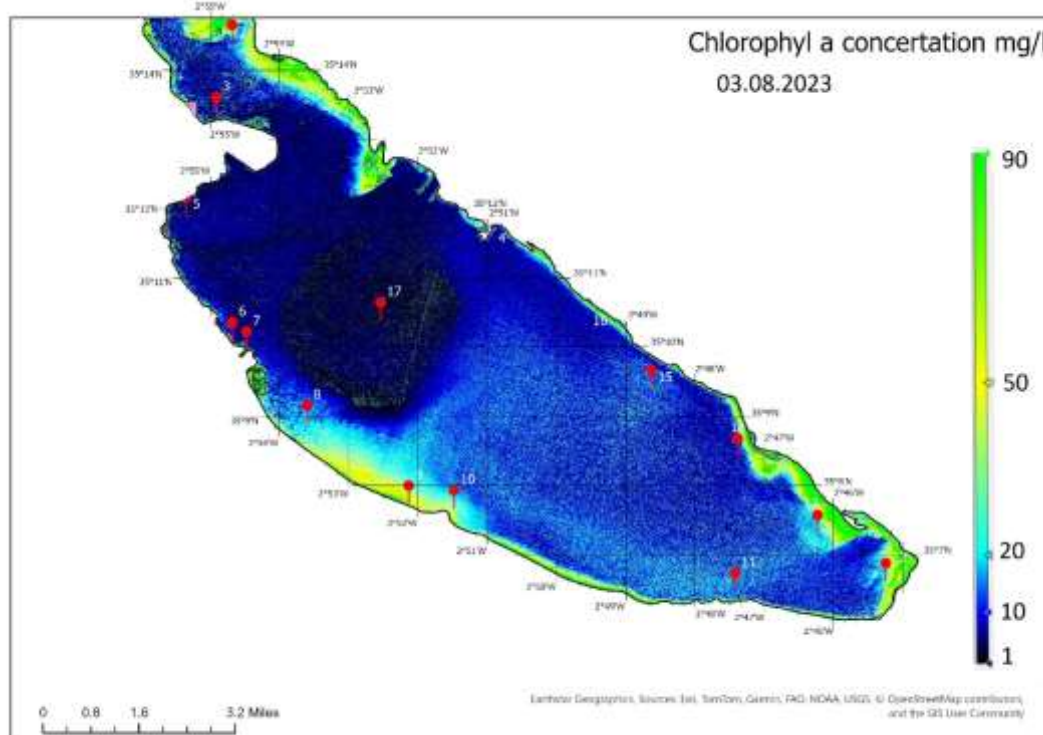


Fig. 4. Chlorophyll-a concentration retrieved from Sentinel - 2 data (03.08.2023).

The performed correlation analysis between the *in situ* and satellite-derived data revealed a high relationship of chlorophyll-a concentrations during the summer ($r = 0.63$), a moderate relationship during the spring ($r = 0.46$), and a low relationship during the winter sampling period ($r = 0.31$).

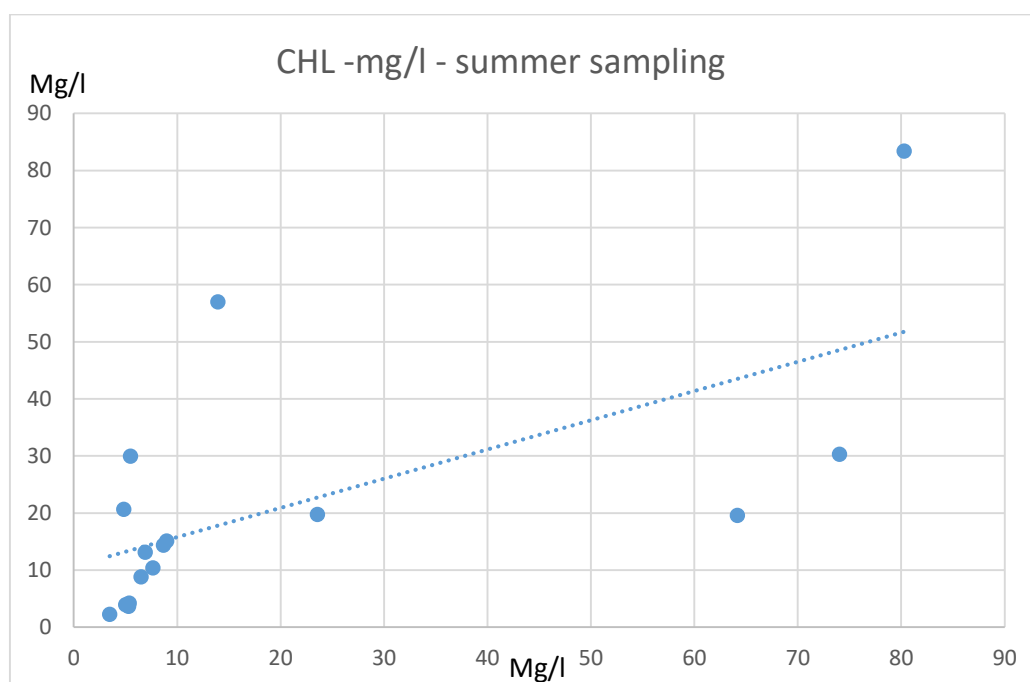


Fig. 5. Correlation between in situ values of chlorophyll and Sentinel 2 MSI data generated with C2X algorithm in C2RCC processor (summer sampling).

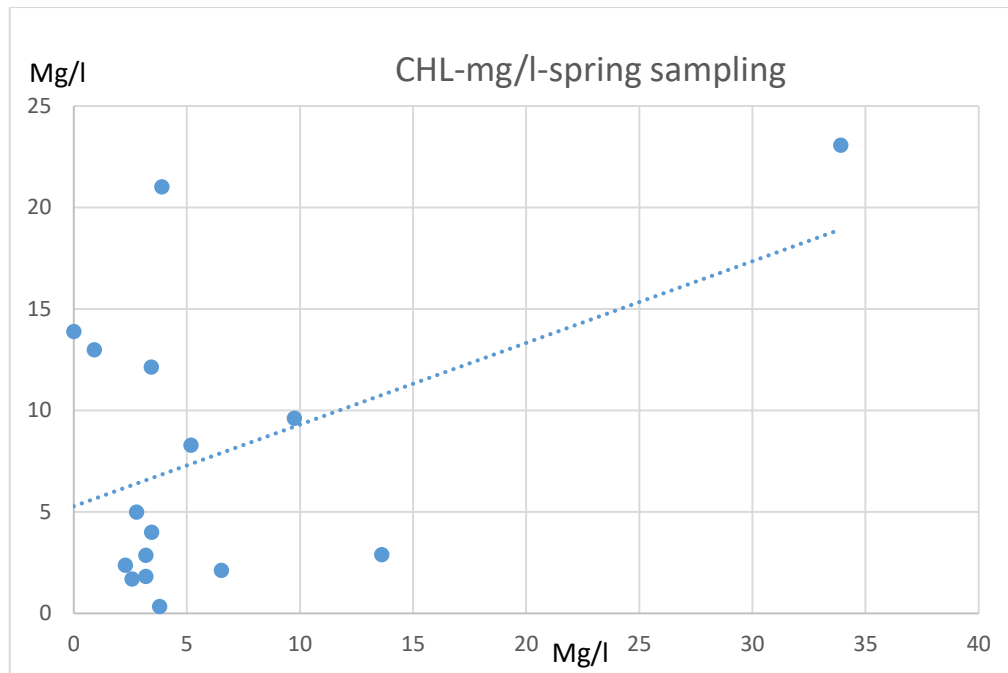


Fig. 6. Correlation between in situ values of chlorophyll and Sentinel 2 MSI data generated with C2X algorithm in C2RCC processor (spring sampling).

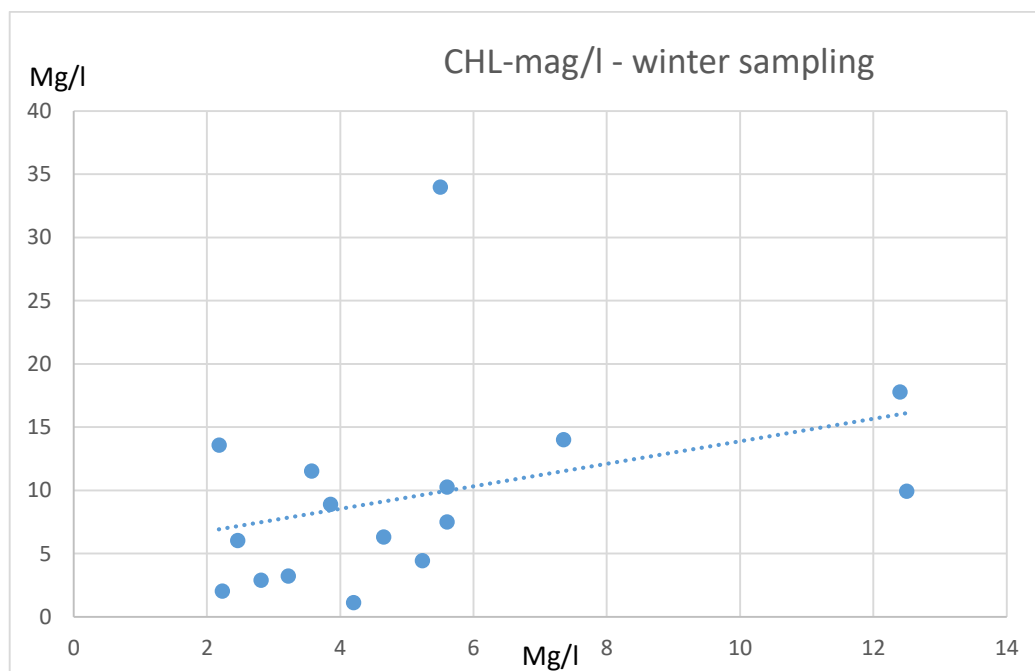


Fig. 7. Correlation between in situ values of chlorophyll and Sentinel 2 MSI data generated with C2X algorithm in C2RCC processor (winter sampling).

Chlorophyll-a concentrations during the summer and spring sampling campaigns revealed similar mean values between Sentinel-2 data (21.0368 mg/L) and *in situ* data (20.26938 mg/L), as well as comparable standard deviation (SD) values—26.67 for the *in situ* data and 21.58 for the Sentinel-2 data, although the *in situ* SD was slightly higher. The same conclusion applies to the spring data, which

showed mean values of 7.743125 mg/L for the Sentinel-2 data and 6.15125 mg/L for the *in situ* data; again, the *in situ* data exhibited a slightly higher SD.

The mean chlorophyll-a concentrations in winter were also comparable, with values of 9.60 mg/L according to Sentinel-2 data and 5.20 mg/L based on *in situ* measurements; however, in contrast to the previous two sampling periods, the SD of the satellite-derived data during winter was higher than that of the *in situ* data (8.04 mg/L compared to 3.17 mg/L).

For comparison between the two measurement methods in each sampling period, a paired two-sample *t*-test for means was conducted. The analysis did not reveal substantial differences for the summer and spring datasets; however, in contrast to these periods, the winter sampling data showed statistically significant differences between values obtained using the two measurement methods (t Stat = -2.33043, $P(T \leq t)$ two-tail = 0.034151, t Crit. = 1.75, $n = 16$).

t-Test: Paired Two Sample for Means		
	Variable 1	Variable 2
Mean	20.26938	21.03688
Variance	711.6453	465.7864
Observations	16	16
Pearson Correlation	0.632081	
Hypothesized Mean Difference	0	
df	15	
t Stat	-0.14478	
P(T<=t) one-tail	0.443404	
t Critical one-tail	1.75305	
P(T<=t) two-tail	0.886808	
t Critical two-tail	2.13145	

Fig. 8. Test: Paired Two Sample for Means – summer data.

t-Test: Paired Two Sample for Means		
	Variable 1	Variable 2
Mean	6.15125	7.743125
Variance	65.81365	50.35646
Observations	16	16
Pearson Correlation	0.460228	
Hypothesized Mean Difference	0	
df	15	
t Stat	-0.80108	
P(T<=t) one-tail	0.217795	
t Critical one-tail	1.75305	
P(T<=t) two-tail	0.435591	
t Critical two-tail	2.13145	

Fig. 9. Test: Paired Two Sample for Means – spring data.

t-Test: Paired Two Sample for Means		
	Variable 1	Variable 2
Mean	5.209375	9.60375
Variance	10.06835	64.75596
Observations	16	16
Pearson Correlation	0.351171	
Hypothesized Mean Difference	0	
df	15	
t Stat	-2.33043	
P(T<=t) one-tail	0.017076	
t Critical one-tail	1.75305	
P(T<=t) two-tail	0.034151	
t Critical two-tail	2.13145	

Fig. 10. Test: Paired Two Sample for Means – winter data.

CONCLUSION

Taking into consideration the size of the Nador Lagoon, both measurement methods reveal the heterogeneity of water conditions and the complex spatial and temporal distribution of chlorophyll-a concentrations. However, the mean chlorophyll-a values derived from satellite data were higher than those obtained using traditional monitoring methods, indicating a lower trophic state when compared with the *in situ* data.

The observed differences between the two datasets may be attributed to the time lag between field sampling (*in situ* measurements) and satellite image acquisition, which can reach up to four days. This temporal mismatch can reduce data comparability, as water quality parameters may change rapidly due to meteorological conditions, particularly variations in water temperature, as well as wind strength and direction.

Satellite-derived estimates may also be influenced by the hydromorphological characteristics of the lagoon, such as water depth and transparency. For example, in the shallow areas of the lagoon, chlorophyll-a concentrations can be affected by the presence of submerged or emergent macrophyte vegetation, as well as by bottom reflectance. In the case of the Nador Lagoon, most sampling locations are situated close to the shoreline, where these factors can significantly influence the reflectance values of the corresponding satellite pixels.

Despite these limitations, the statistical analysis revealed a moderate positive correlation between *in situ* measured chlorophyll-a concentrations and satellite-derived data during the summer and spring sampling campaigns. In contrast, although a slight positive correlation was observed during the winter sampling period, the paired two-sample *t*-test indicated statistically significant differences between the two datasets.

In conclusion, chlorophyll-a concentrations obtained using both methods showed generally comparable results. Remote sensing based on Sentinel-2 MSI data can therefore be considered

a valuable, time- and cost-efficient supplementary tool for water quality monitoring, capable of identifying negative trends in water quality and trophic status. This approach is particularly useful for large or remote water bodies, where frequent traditional monitoring is time-consuming and costly; however, local validation remains essential for reliable application.

Declaration by Authors

Ethical Approval: Approved

Acknowledgement: None

Source of Funding: None

Conflict of Interest: The authors declare no conflict of interest.

REFERENCES

- Ahmed, M. H., & Donia, N. S. (2007). Spatial investigation of water quality of Lake Manzala using GIS techniques. *Egyptian Journal of Remote Sensing and Space Sciences*, 10, 63–86.
- Ahmed, M. H., & El-Leithy, B. (2008). Utilization of satellite images for monitoring the environmental changes and development in Lake Mariout during the past four decades. In *Proceedings of the International Conference “Environment Is a Must”* (pp. xx–xx), Alexandria, Egypt.
- Albright, T. P., Moorhouse, T. G., & McNabb, T. J. (2004). The rise and fall of water hyacinth in Lake Victoria and the Kagera River Basin, 1989–2001. *Journal of Aquatic Plant Management*, 42, 73–84.
- Ansper, A., & Alikas, K. (2018). Retrieval of chlorophyll-a from Sentinel-2 MSI data for the European Union Water Framework Directive reporting purposes. *Remote Sensing*, 11(1), 64. <https://doi.org/10.3390/rs11010064>
- Carlson, R. E. (1977). A trophic state index for lakes. *Limnology and Oceanography*, 22(2), 361–369.
- Coluzzi, R., Imbrenda, V., Lanfredi, M., & Simoniello, T. (2018). A first assessment of the Sentinel-2 Level-1C cloud mask product to support informed surface analyses. *Remote Sensing of Environment*, 217, 426–443. <https://doi.org/10.1016/j.rse.2018.08.009>
- Dakki, M. (2003). *Diagnostic pour l'aménagement des zones humides du Nord-Est du Maroc: Sebkhia Bou Areg (lagune de Nador)*. MedWetCoast Maroc.
- El Madani, F. (2012). *[Doctoral dissertation, Université Mohammed I]*. Faculté des Sciences, Oujda, Morocco.
- Graetz, R. (1990). Remote sensing of terrestrial ecosystem structure: An ecologist's pragmatic view. In R. Hobbs & H. Mooney (Eds.), *Remote sensing of biosphere functioning* (pp. 5–30). Springer.
- Jaafour, S., Yahyaoui, A., Sadak, A., Bacha, M., & Amara, R. (2015). Fish assemblages of a shallow Mediterranean lagoon (Nador, Morocco): An analysis based on species and functional guilds. *Acta Ichthyologica et Piscatoria*, 45(2), 193–206.
- Jankauskaite, G., Pérez, R., & Soria, J. (n.d.). *Trophic state changes in the Nador Lagoon (Morocco) determined by remote sensing using Landsat-8*.



- Jeyar, M., Chaabelasri, E., & Salhi, N. (2015). Numerical investigation of new alternative Nador Lagoon inlet relocation. *International Journal of Fluid Mechanics Research*, 42(5), 395–411.
- Jouamaa, A., Gharbi, M., Noon, V., & Emad, A. (n.d.). *The Marchica Lagoon area in the context of climate change: Exploring adaptation and mitigation policies*.
- Karim, H., Ahmed, D., Mohammed, I., & Benyounes, D. (2015). Circulation marine de la lagune de Nador (Maroc) par modélisation hydrodynamique. *European Scientific Journal*, 11, 418–428.
- Kazakov, S., Biserkov, V., Pehlivanov, L., & Nedkov, S. (2020). Trophic status assessment of small turbid lakes comparing remote sensing and in situ data: Case study at the Lower Danube floodplain. *Aerospace Research in Bulgaria*, 32, 105–118.
- Maanan, M., Saddik, M., Maanan, M., Chaibi, M., Assobhei, O., & Zourarah, B. (2015). Environmental and ecological risk assessment of heavy metals in sediments of Nador Lagoon, Morocco. *Ecological Indicators*, 48, 616–626.
- Maicu, F., Abdellaoui, B., Bajo, M., Chair, A., Hilmi, K., & Umgieser, G. (2021). Modelling the water dynamics of a tidal lagoon: The impact of human intervention in the Nador Lagoon (Morocco). *Continental Shelf Research*, 228, 104535. <https://doi.org/10.1016/j.csr.2021.104535>
- Mohamed, N., Driss, N., Nadia, B., Roberto, P., Abdeljaouad, L., & Nor-dine, R. (2017). Characterization of the new status of Nador Lagoon (Morocco) after the implementation of the management plan. *Journal of Marine Science and Engineering*, 5(1), 7. <https://doi.org/10.3390/jmse5010007>
- Nachite, D., Maziane, F., Anfuso, G., & Macias, A. (2018). Beach litter characteristics along the Moroccan Mediterranean coast: Implications for coastal zone management. In *Beach management tools – Concepts, methodologies and case studies* (pp. 795–819). Springer.
- Quaranta, G., Bloundi, M. K., Duplay, J., & Clauer, N. (2021). The eutrophication process of Nador's Lagoon (Morocco) evaluated by the life cycle impact assessment method. *Arabian Journal of Geosciences*, 14, 1–8. <https://doi.org/10.1007/s12517-021-07253-x>
- Toming, K., Kutser, T., Laas, A., Sepp, M., Paavel, B., & Noges, T. (2016). First experiences in mapping lake water quality parameters with Sentinel-2 MSI imagery. *Remote Sensing*, 8(8), 640. <https://doi.org/10.3390/rs8080640>
- UNEP. (2005). *Africa's lakes: Atlas of our changing environment*. United Nations Environment Programme.

How to cite this article:

Ivanov, M., Varadinova, E., Dalgacheva, V., El Mekki, O., Tuefekchiev, K., & Karadzhov, V. (2025). Remote sensing based assessment of the water quality in Nador Lagoon, Morocco. *International Journal of Digital Research*, E-ISSN: 3033-179X, 1(4): 106-119. <https://doi.org/10.63711/ijdr.net20250407>

