Open Journal of Marine Science, 2026, 16(4), 213-223
https://www.scirp.org/journal/ojms
ISSN Online: 2161-7392
ISSN Print: 2161-7384

# Contribution of Remote Sensing to the Assessment of Colored Dissolved Organic Matter (CDOM): Case Study of the Adjin Lagoon

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**How to cite this paper:** Jeanne, K.M., Adonija, K. and Bertrand, B.K.Y. (2026) Contribution of Remote Sensing to the Assessment of Colored Dissolved Organic Matter (CDOM): Case Study of the Adjin Lagoon. *Open Journal of Marine Science*, **16**, 213-223.
https://doi.org/10.4236/ojms.2026.164013

**Received:** July 2, 2026
**Accepted:** August 23, 2026
**Published:** August 26, 2026

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## Abstract

Lagoons and coastal ecosystems in tropical regions are increasingly subjected to strong anthropogenic pressures, making water quality monitoring particularly crucial. Colored Dissolved Organic Matter (CDOM) is a key indicator of water quality due to its influence on optical properties and biogeochemical processes. This study aims to assess the contribution of remote sensing to the estimation of CDOM in the Adjin Lagoon, located in southeastern Côte d'Ivoire. Multispectral Sentinel-2 images covering the period 2018-2024, processed using the Case 2 Regional CoastColour (C2RCC) algorithm adapted for optically complex waters, were combined with in situ measurements collected in June 2024 to analyze the spatio-temporal variability of CDOM and its relationship with chlorophyll-*a*. The results reveal marked seasonal variations in CDOM and chlorophyll concentrations. Chlorophyll peaks observed in January, May, and October are associated with phytoplankton blooms driven by favorable light and nutrient conditions, whereas CDOM concentrations are mainly controlled by terrestrial inputs, with maximum values recorded during the rainy season, particularly in August (0.86 $m^{-1}$). The correlation between CDOM and chlorophyll is weak and positive ($r = 0.27$), indicating partially independent dynamics. Validation using in situ data shows excellent agreement with satellite-derived estimates, with a negligible difference of approximately 0.02 $m^{-1}$, confirming the reliability of remote sensing for CDOM assessment in tropical lagoon environments. This study highlights the potential of remote sensing for monitoring lagoon water quality and provides useful insights for the sustainable management of coastal ecosystems in Côte d'Ivoire.

**Keywords**

Colored Dissolved Organic Matter (CDOM), Case-2 Regional Coast Colour (C2RCC), Remote Sensing, Adjin Lagoon, Côte d'Ivoire

## 1. Introduction

The progressive degradation of lagoon and coastal ecosystems has become a major concern, particularly in tropical regions subjected to strong anthropogenic pressures. In Côte d'Ivoire, lagoons play a crucial ecological and socio-economic role by providing fisheries production, biogeochemical regulation, and livelihoods for surrounding communities. However, rapid urbanization, domestic and agricultural discharges, as well as hydroclimatic changes, are contributing to the deterioration of water quality in these aquatic environments [1].

Among the key indicators of lagoon water quality is Colored Dissolved Organic Matter (CDOM). CDOM strongly absorbs light in the ultraviolet and blue regions of the electromagnetic spectrum, thereby reducing light penetration in the water column and directly influencing biogeochemical processes, particularly primary production. High CDOM concentrations are generally associated with significant terrestrial inputs, organic matter degradation, and eutrophication processes, making CDOM a relevant tracer of the ecological status of coastal and lagoon waters [2].

The assessment of CDOM using conventional in situ methods remains limited by high costs, low spatial coverage, and temporal discontinuities in field campaigns. In this context, ocean color remote sensing emerges as an effective alternative for synoptic and temporal monitoring of water quality. Multispectral sensors, such as those onboard Sentinel-2 satellites, combined with bio-optical algorithms adapted to optically complex waters, allow the estimation of CDOM and chlorophyll concentrations at spatial and temporal resolutions suitable for lagoon environments.

The present study aims to evaluate the contribution of remote sensing to CDOM estimation in the Adjin Lagoon by combining Sentinel-2 satellite data and in situ measurements. Specifically, the objectives of this research are to:

Characterize the spatio-temporal distribution of CDOM through a series of maps over the study period;

Analyze the relationship between CDOM and chlorophyll to better understand the biogeochemical processes controlling water color in the lagoon;

Validate satellite-derived estimates using field observations.

## 2. Methodology

### 2.1. Study Area

The study area is located in southeastern Côte d'Ivoire, between latitudes 5˚21'N and 5°28'N and longitudes 3°49'W and 3°58'W (Figure 1). It is situated to the north of the Ebrié Lagoon, from which it is separated by the Potou Lagoon.

The Adjin and Potou lagoons are connected by a natural channel. The climate of the study area is equatorial, characterized by four distinct seasons: a long dry season from December to March, a long rainy season from April to July, a short dry season from August to September, and a short rainy season from October to November.

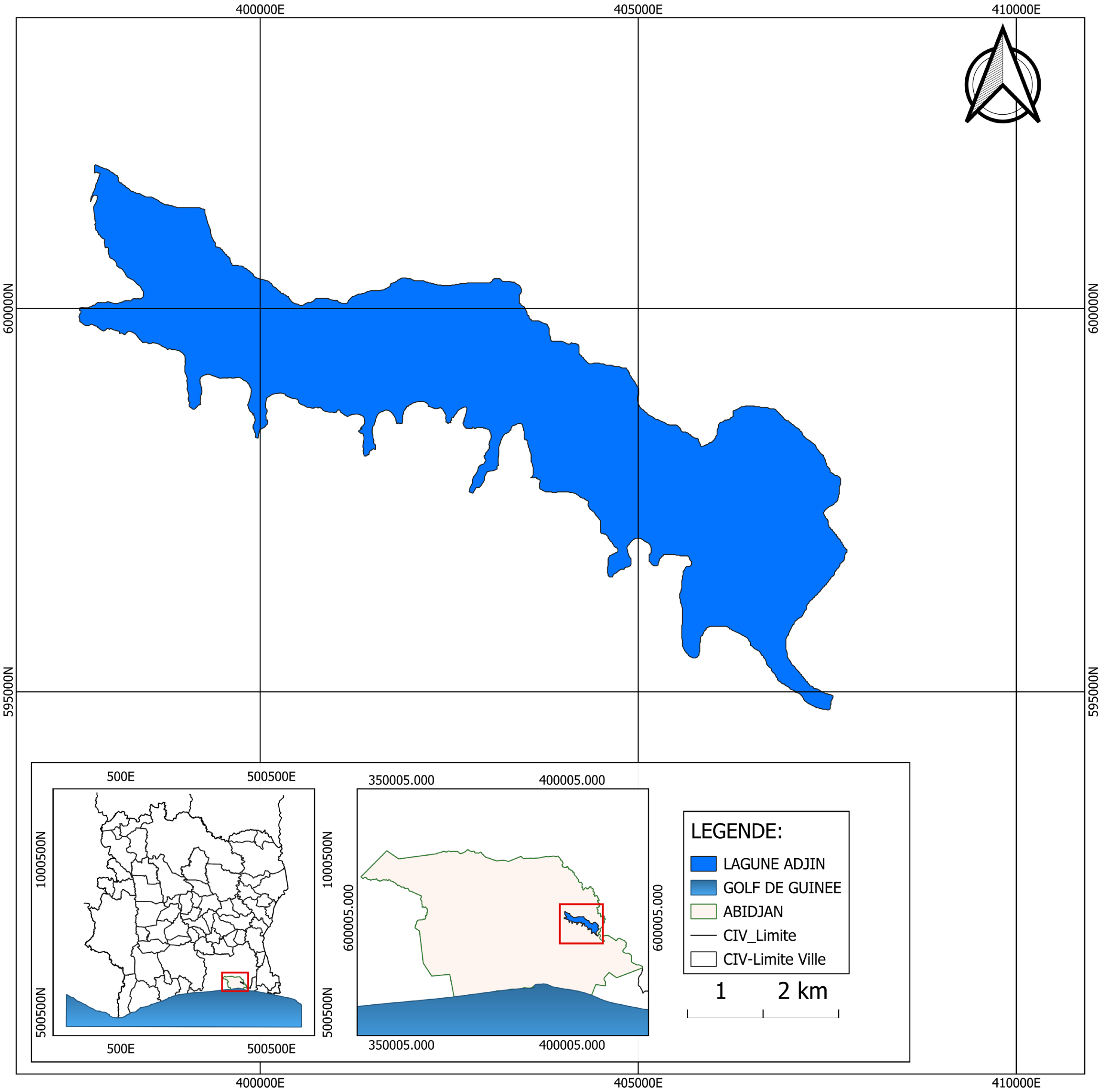


Figure 1. Map of the study area.

## 2.2. Data Source

A preliminary and essential step of this study was to identify the water type of the study area. The Adjin Lagoon is classified as Case 2 water, characterized by the simultaneous presence of several optically active constituents, including colored dissolved organic matter (CDOM), chlorophyll-*a*, and suspended particulate matter. This classification encompasses all the parameters investigated and justifies the methodological approach adopted for the retrieval of CDOM and chlorophyll-*a* (**Figure 2**). This study is based on two complementary data sources: satellite data and *in situ* measurements. The satellite data were acquired from the MultiSpectral Instrument (MSI) onboard the Sentinel-2 satellite and consist of Level-1C products. This sensor was selected because of its appropriate spatial (10 - 20 m) and temporal (5-day revisit) resolution, its ability to capture the optical properties of Case 2 waters, particularly those related to CDOM, and the free availability of its data. Daily satellite observations covering the 2018-2024 period were used for image processing and analysis. The *in situ* data were collected during a field sampling campaign conducted in Adjin Lagoon. A total of 20 sampling stations were surveyed on 10 June 2024 to measure CDOM and chlorophyll-*a* concentrations. These field measurements were used to calibrate and validate the satellite-derived retrieval models.

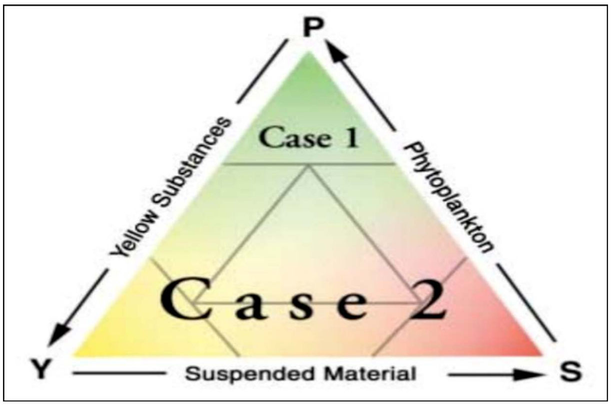


**Figure 2.** Classification of Case 1 and Case 2 waters (IOCCG, 2006).

### 2.3. Data Analysis

The Sentinel-2 images were pre-processed to correct for errors and reduce noise, ensuring improved radiometric and geometric quality. The retrieval of optical parameters is based on the C2RCC algorithm, which is specifically adapted to Case 2 waters. This algorithm allows the estimation of CDOM, chlorophyll-*a*, and suspended particulate matter concentrations. In contrast, water samples were stored in the dark and kept at low temperature to minimize the effects of temperature and photodegradation on CDOM. Analyses were performed on the same day after the samples had returned to room temperature. Prior to measurement, samples were filtered through 0.2 μm filters to remove particles that could interfere with the measurements. CDOM was measured using spectrophotometry with a PerkinElmer Lambda 20 spectrophotometer. The methodological framework guiding data acquisition, processing, and analysis is presented in **Table 1**.

**Table 1.** Methodological workflow for data processing.

| Data | Data processing | |
|---|---|---|
| | *Satellite Data* | Water samples |
| Data processing and analysis | Geometric correction<br>Study area extraction<br>Band resampling to 60 m spatial resolution<br>Retrieval of water quality parameters using the C2RCC algorithm<br>CDOM and chlorophyll-*a* data | Storage of samples at controlled temperature<br>Filtration of samples Spectrophotometer preparation step<br>CDOM measurement using the PerkinElmer Lambda 20 spectrophotometric method<br>Numerical value of CDOM concentration |

## 3. Results

### 3.1. Spatio-Temporal Distribution of CDOM and Chlorophyll-*a*

The seasonal analysis of chlorophyll-*a* concentrations reveals marked monthly variability. During the dry season, a peak is observed in January (33.2 mg/m$^3$), followed by relatively high values in February (25.26 mg/m$^3$) and March (25.55 mg/m$^3$), while November (24.78 mg/m$^3$) and December (23.72 mg/m$^3$) show moderate concentrations. The lowest values are recorded in July (21.48 mg/m$^3$) and August (23.54 mg/m$^3$), likely associated with thermal stratification and reduced nutrient inputs. During the rainy season, chlorophyll-*a* concentration decreases in June (24.11 mg/m$^3$) before increasing sharply in September (27.13 mg/m$^3$). A maximum peak is reached in October (33.34 mg/m$^3$), corresponding to the end of the main rainy season. Moderate concentrations are observed in March-April (~25.5 mg/m$^3$), followed by another peak in May (32.94 mg/m$^3$), associated with favorable light and nutrient conditions (**Figure 3**).

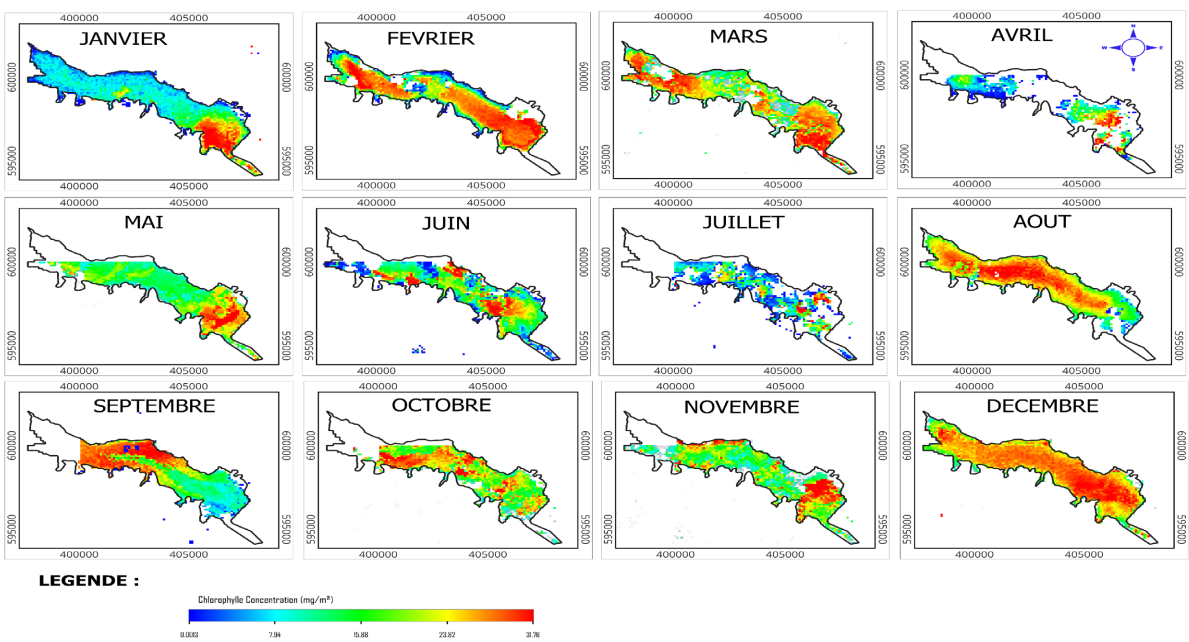


**Figure 3.** Monthly variability map of chlorophyll concentration from 2018-2024.

The spatio-temporal evolution of CDOM in the Adjin Lagoon reveals marked seasonal variability. During the dry season, concentrations are relatively high and stable in January and February (0.810 $m^{-1}$), with a slight increase in March (0.815 $m^{-1}$), likely linked to the onset of rainfall inputs. A gradual decrease is observed in November (0.751 $m^{-1}$) and December (0.734 $m^{-1}$), reflecting a reduction in dissolved organic matter inputs. The lowest monthly value is recorded in July (0.709 $m^{-1}$), possibly related to thermal stratification and reduced mixing processes. A pronounced increase is observed in August (0.861 $m^{-1}$), associated with the beginning of rainfall and continental runoff. During the wet season, CDOM concentrations increase in June (0.777 $m^{-1}$) and reach high values in September (0.837 $m^{-1}$), driven by riverine inputs and watershed leaching. A slight decline is then observed in October (0.751 $m^{-1}$), followed by a renewed increase in May (0.824 $m^{-1}$), reflecting intermittent inputs of dissolved organic matter (**Figure 4**).

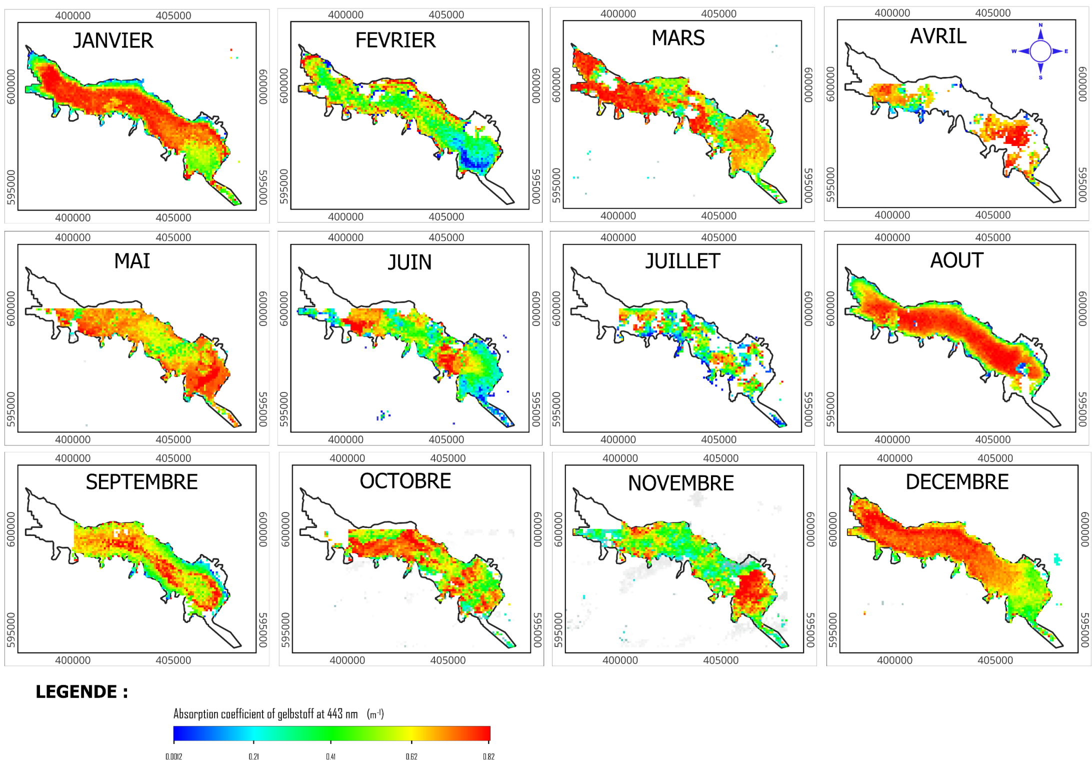


**Figure 4.** Map of the monthly variability of CDOM concentration from 2018 to 2024.

## 3.2. Correlation between CDOM and Chlorophyll-*a*

The correlation analysis between chlorophyll-*a* (CHL-*a*) and colored dissolved organic matter (CDOM) derived from satellite data reveals a weak positive correlation ($r = 0.27$). This value indicates that an increase in one variable is sometimes associated with an increase in the other, but without a consistent or systematic relationship.

Indeed, chlorophyll-*a* is an indicator of phytoplankton biomass, the degradation of which contributes to the production of colored dissolved organic matter.

Thus, an increase in algal biomass can lead, after partial transformation and mineralization of organic matter, to an increase in CDOM in the aquatic environment. However, this production is not necessarily synchronous with phytoplankton growth phases, which may explain the weak correlation observed. The trend line shows a generally positive orientation, confirming this weak dependence. The twelve points in the graph correspond to the monthly averages from January to December. This low correlation suggests that CDOM and chlorophyll dynamics are partly independent and influenced by distinct environmental factors (**Figure 5**).

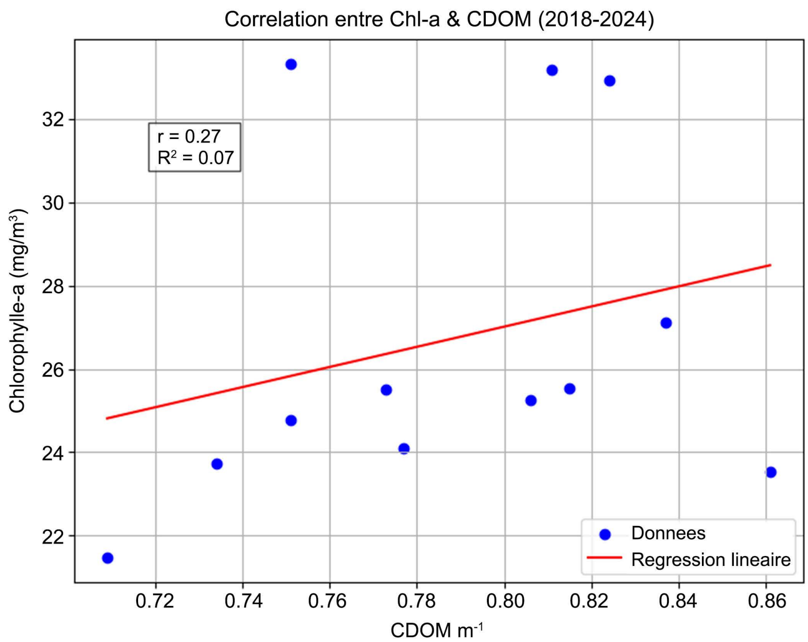


**Figure 5.** Correlation plot between CDOM and chlorophyll.

### 3.3. Validation of Satellite Data Using *In-Situ* Data

As part of the validation of the processed data, a comparative analysis was conducted between the mean *in-situ* CDOM concentrations measured and analyzed in the laboratory, and those estimated from remote sensing. This comparison was limited to June, which corresponds to the last field sampling campaign.

To ensure consistency between *in-situ* measurements and satellite-derived estimates, an empirical calibration relationship was established between laboratory-measured concentrations (mg/L) and the CDOM absorption coefficient ($m^{-1}$). This relationship, derived from linear regression, allowed the conversion of *in-situ* values into optical units. Thus, an average concentration of 15.446 mg/L corresponds to an estimated value of 0.75 $m^{-1}$.

The relationship is expressed as:

$$a(\lambda) = k \times C$$

where:

- $a(\lambda)$ is the absorption coefficient at a given wavelength ($m^{-1}$),

- $C$ is the concentration of the studied substance (mg/L),
- $k$ is the empirical conversion coefficient ($m^{-1}·mg^{-1}·L$), determined from field data.

In this study, the calibration performed on *in-situ* data yielded an estimated value of $k \approx 0.0485$. The mean CDOM concentration obtained from remote sensing is 0.777 $m^{-1}$. In comparison, *in-situ* samples yield a mean concentration of 15.446 mg/L, which corresponds to 0.75 $m^{-1}$. The difference between these two values is only 0.02 $m^{-1}$, representing a negligible discrepancy. This small difference highlights an excellent agreement between the two approaches for estimating CDOM, demonstrating their consistency and complementarity.

Such validation strengthens the reliability of remote sensing methods, which can be effectively used for the spatio-temporal monitoring of water quality parameters over large areas, where systematic *in-situ* sampling would be less feasible.

## 4. Discussion and Conclusion

This study aimed to assess CDOM levels and compare these concentrations with chlorophyll (CHL) in the aquatic environment of Adjin, a coastal village in Côte d'Ivoire [3]. The results reveal a complex relationship between these two variables, influenced by a variety of environmental factors. This section highlights the main findings derived from the data, compares them with previous studies, and discusses the limitations and implications of the results.

The analysis of the spatio-temporal variability of CDOM and chlorophyll concentrations showed significant seasonal fluctuations. Chlorophyll peaks observed in January, May, and October can be explained by phytoplankton bloom events, favored by optimal light availability and nutrient conditions. These findings are consistent with [4], who demonstrated that seasonal cycles and local environmental conditions strongly influence phytoplankton variability, as well as with [5], who highlighted the role of light and nutrient availability in regulating chlorophyll dynamics in coastal and lagoon systems.

In contrast, the spatio-temporal variability of CDOM appears to be less directly linked to these same factors. Although CDOM can originate from phytoplankton degradation, its concentration is also strongly influenced by allochthonous inputs of terrestrial organic matter [6]. In the Adjin context, this is likely explained by organic matter inputs from the surrounding watershed, particularly following heavy rainfall events that enhance soil leaching. Terrigenous inputs therefore play a key role in CDOM dynamics. As observed in other tropical regions, the rainy season in Côte d'Ivoire often coincides with increased terrestrial organic matter inputs, which may explain the high CDOM concentrations recorded in August and September [7].

In this study, CDOM concentrations showed significant annual variability, with peaks in August and September, consistent with the findings of [7] regarding the importance of terrigenous inputs in tropical coastal systems. CDOM concentrations in ocean waters of the Gulf of Guinea range from 0.0024 to 0.113 $m^{-1}$, which is broadly consistent with the values observed in this study.

The weak positive correlation (r = 0.27) between monthly CDOM and chlorophyll concentrations suggests only a partial interaction between these two variables. This correlation indicates that increases in phytoplankton biomass may sometimes be accompanied by increases or decreases in CDOM, although this relationship is not systematic. Previous studies have also reported complex relationships between CDOM and chlorophyll due to variability in sources and transport mechanisms of dissolved organic matter in coastal environments [8].

In this study, the highest CDOM concentrations were observed in August (0.86 $m^{-1}$), corresponding to the period of strongest terrestrial inputs, confirming that CDOM in the Adjin Lagoon is strongly influenced by allochthonous inputs, likely associated with surface runoff following rainfall events [9].

Finally, the comparison between *in-situ* measurements collected in June and satellite-derived estimates from Sentinel-2 imagery processed using the C2RCC algorithm shows excellent agreement, with CDOM concentrations of 0.75 $m^{-1}$ measured in the field and 0.77 $m^{-1}$ estimated from satellite data. This small difference (≈0.02 $m^{-1}$) confirms the reliability of remote sensing for CDOM assessment in coastal environments, as also reported by [10], although some limitations remain under complex atmospheric conditions. This study highlights the importance of assessing CDOM in coastal waters to better understand biogeochemical dynamics in these complex ecosystems. Although a weak positive correlation was observed between CDOM and chlorophyll concentrations, the findings also emphasize the need for satellite data validation and further research to disentangle the complex interactions between these two variables. The sustainable management of the Adjin coastal ecosystem will require more integrated studies that take into account seasonal variability, terrestrial inputs, and interactions among the different ecosystem components. The validation of remote sensing data showed an overall good agreement between satellite-derived and *in-situ* measurements, although minor discrepancies were observed, particularly during periods of high turbidity or unfavorable atmospheric conditions. This process improved the accuracy of the results and confirmed the contribution of remote sensing to water quality assessment. It also highlights the importance of integrating regular field campaigns to ensure the reliability of satellite-derived data, especially in coastal environments characterized by complex dynamics. One of the main limitations of this study lies in the variability of CDOM sources, which are not solely linked to phytoplankton production. In addition, environmental factors not considered in this work, such as water temperature, pH, and nutrient inputs, may have influenced the results. A more comprehensive analysis including these parameters would be necessary to better understand the underlying mechanisms driving the observed variations. The monthly and interannual data showed that chlorophyll and CDOM concentrations fluctuate over time, but it remains difficult to precisely determine the causes of these fluctuations without more frequent sampling and a longer monitoring period. Future work could include more regular field campaigns and the incorporation of additional parameters such as nutrient loads and temperature.

## Acknowledgements

The completion of this study would not have been possible without the valuable support of the GMES & Africa programme, through the grant awarded in the framework of my research work. I would like to express my sincere gratitude to this African initiative for its commitment to the development of scientific capacity and the use of space technologies for the sustainable management of environmental resources in Africa. The support provided by the GMES & Africa project played a decisive role in the conduct of this research on the assessment of Colored Dissolved Organic Matter (CDOM) in the Adjin Lagoon using remote sensing techniques. Thanks to this grant, several key stages of the project were successfully carried out under improved conditions, including data acquisition, field campaigns, laboratory analyses, and the processing of Sentinel-2 satellite imagery.

This support also contributed to strengthening the technical and scientific capacities applied in this study, particularly in the fields of environmental remote sensing, geospatial data processing, and coastal water quality analysis. The project facilitated access to the necessary resources for *in-situ* data validation and the use of appropriate methodological tools for Case-2 waters. Beyond the financial aspect, this grant represents a significant contribution to the development of applied scientific research in Côte d'Ivoire and to the promotion of innovative solutions based on space technologies for monitoring lagoon ecosystems. It has therefore played a major role in the completion of this work and in the enhancement of the results obtained. I would like to renew my sincere thanks to the GMES & Africa programme, as well as to all institutions, partners, and stakeholders involved in this initiative, for their trust, support, and commitment to research and scientific innovation in Africa.

## Author Contributions

Conceptualization, K.M.J.; methodology, K.A., and B.K.Y.B.; investigation, K.M.J., K.A., and B.K.Y.B.; data curation and formal analysis, K.M.J., K.A., and B.K.Y.B.; supervision, K.M.J; writing original draft preparation, K.M.J; writing review and editing, K.M.J and B.K.Y.B.; visualization, K.M.J.; All authors have read and agreed to the published version of the manuscript.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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