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Projet GIRE-GUIERS*

Gestion Intégrée des Ressources en Eau et de l'Environnement du lac de Guiers

ATELIER DE LANCEMENT

Salle du Conseil - FST/UCAD – 23 Février 2013

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TIGER AFRICA

UEMOA

* *Avec l'appui de l'Agence Spatiale Européenne et du programme PAES de l'UEMOA*

En 2002, l'Agence Spatiale Européenne (ESA) a lancé l'initiative TIGER en réponse à l'appel du Sommet mondial de Johannesburg sur le développement durable (SMDD). L'objectif global de cette initiative est d'aider les pays africains à surmonter les problèmes de gestion intégrée de leurs ressources en eau en exploitant les avantages de la technologie des satellites d'observation de la Terre dans la collecte, l'analyse et l'utilisation de l'information géo-spatiale.

L'initiative TIGER s'est développée grâce à la contribution de nombreux partenaires africains et internationaux tels que la Facilité Africaine de l'eau, la Conférence ministérielle africaine sur l'eau, la Commission de l'Union africaine, le Programme Ramsar, le Ministère de l'Eau et des Forêts de l'Afrique du Sud, la Commission économique des Nations Unies pour l'Afrique, le Centre Royal de Télédétection spatiale du Maroc, l'AGRHYMET, l'Observatoire régional du Sahara et du Sahel, la Commission de recherche sur l'eau de l'Afrique du Sud, l'UNESCO-PHI, le CCI, l'Agence spatiale canadienne, les autorités nationales de l'eau, ainsi que les universités et le secteur privé.

Les autorités sénégalaises accordent une grande importance au contrôle, au suivi et à la protection des ressources en eau du pays. Un accent particulier est mis sur la gestion intégrée et durable des ressources en eau du Lac de Guiers qui est considérée comme une question de haute priorité nationale et qui a justifié la création en 2010 de l'Office du Lac de Guiers (OLAG).

C'est dans ce contexte que le Laboratoire de Télédétection Appliquée (LTA) de l'Institut des Sciences de la Terre (IST) a initié le projet « GIRE/GUIERS » d'une durée de 3 ans, avec les objectifs suivants :

Objectif général :

- Mise en place d'un Système d'Informations Géo-Spatiales (SIG) pour la gestion intégrée des ressources en eau du lac. La base de données SIG prendra en compte le fonctionnement hydrologique du lac (dynamique spatio-temporelle), la qualité des eaux du lac, ainsi que l'évolution naturelle et anthropique de l'environnement du lac.

Objectifs spécifiques :

- Etude de la variabilité spatio-temporelle du bilan des ressources hydriques du lac, en liaison avec les changements climatiques ;
- Détermination des sources de pollution dans le système lacustre pour l'élaboration de mesures de protection ;
- Suivi environnemental du lac à travers des facteurs physiques et biologiques ; sur la qualité de l'eau
- Evaluation des risques sanitaires liés à l'impact des activités humaines autour du lac ;
- Propositions de stratégies de sauvegarde et de restauration de l'environnement du lac.

Le projet GIRE-GUIERS est né du projet TIGER/GLIWaRM (Guiers Lake Integrated Water Resources Management) qui bénéficie de l'accès gratuit aux données satellitaires de l'ESA et du Plan de renforcement des capacités de TIGER.

Ainsi, des données radar micro-ondes ASAR/ENVISAT ont été acquises pour la cartographie du plan d'eau et des plantes aquatiques envahissantes. Des données du capteur MERIS du satellite ENVISAT sont également exploitées pour le suivi de la qualité des eaux du lac, par l'extraction de paramètres de qualité tels que les concentrations en chlorophylle, oxygène dissous, matières en suspension, matière organique et algues toxiques.

Les paramètres de qualité de l'eau cartographiés avec les données du capteur MERIS de ENVISAT comprennent :

La chlorophylle (Chl-a) :

Elle contribue à la couleur de l'eau. C'est un agent photosynthétique indicateur de la concentration en algues et un paramètre-clé pour l'évaluation de la qualité de l'eau. L'eutrophication des plans d'eau peut être quantifiée en termes de concentration de chlorophylle dans les cellules des algues planctoniques.

- Les substances jaunes (Coloured Dissolved Organic Matter, CDOM ou Gelbstoff) :

Elles affectent la couleur de l'eau. Ce sont des substances organiques biogéniques hétérogènes, solubles dans l'eau. Elles contribuent d'une manière significative à l'absorption de la lumière dans une certaine fourchette de longueur d'onde.

- Les matières en suspension (Total suspended matter, TSM) :
Elles comprennent de la matière organique et inorganique. Elles jouent un rôle important dans la gestion de la qualité de l'eau, dans la mesure où elles sont liées à la production primaire et aux flux de métaux lourds et de micropolluants.

Une quarantaine d'images MERIS pleine résolution, de niveau 2B, ont été acquises dans le cadre du projet TIGER/GLIWaRM. Les données couvrent la période 2003-2010 et comptent au moins 4 images par année dont une image de saison sèche froide, une de saison sèche chaude, une de début de saison des pluies et une de fin de saison des pluies. Cette base de données permet d'évaluer la variabilité saisonnière et inter-annuelle des paramètres de qualité de l'eau.

Les résultats préliminaires du traitement des données MERIS sont résumés ci-après :

- le trend annuel des paramètres de qualité (Chl-a, TSM, CDOM) pour la période 2003-2010 montre que les concentrations en matières en suspension et en substances jaunes sont plus élevées dans les zones nord et centre du lac (fig. 1). Il indique, en outre, que les teneurs en chlorophylle (Chl-a) sont plus élevées le long des lignes de ravage et dans la zone sud du lac ;

- le trend mensuel de la chlorophylle pour la période 2003-2010 montre que les teneurs en Chl-a sont plus élevées aux mois de Mars, Mai et Octobre (fig. 2) ;

- le trend mensuel des matières en suspension (Total suspended matter, TSM) pour la période 2003-2010 (fig. 3) indique que les teneurs en TSM sont plus élevées aux mois de Mars et Août.

Ces résultats, non encore validés sur le terrain, semblent toutefois être en parfaite adéquation avec les données rapportées dans la littérature. Des campagnes de terrain sont programmées pour réaliser des observations environnementales, faire des mesures in-situ de paramètres de qualité, collecter des échantillons d'eau pour des analyses chimiques et bactériologiques.

Les fonds alloués au projet GIRE-GUIERS par l'UEMOA, dans le cadre du Programme d'appui à l'Enseignement Supérieur (PAES), ont permis d'acquérir des radiomètres de terrain TRIOS RAMSES (fig. 4) destinés à réaliser des mesures in-situ de paramètres de qualité de l'eau (chlorophylle, matières en suspension, substances jaunes) qui serviront à la calibration et la validation des données satellitaires MERIS/ENVISAT.

Les fonds PAES/UEMOA serviront également à acquérir des équipements complémentaires (GPS, limnigraphes, échelles limnimétriques, pluviomètres, thalimédes, sonde multiparamètre, verrerie, appareil photo-numérique, groupe électrogène) et à financer d'autres volets du projet (équipements informatiques, analyses chimiques, fonctionnement, frais de missions de terrain, frais d'organisation d'ateliers et de séminaires).

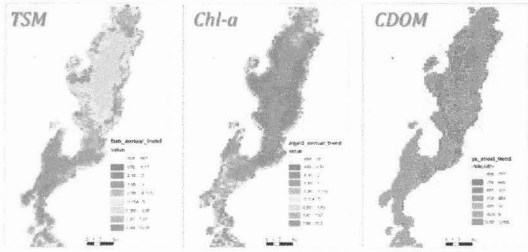

Fig. 1 – Cartographie MERIS du trend annuel des concentrations en chlorophylle (Chl-a), matières en suspension (TSM) et substances jaunes (CDOM) pour la période 2003-2010

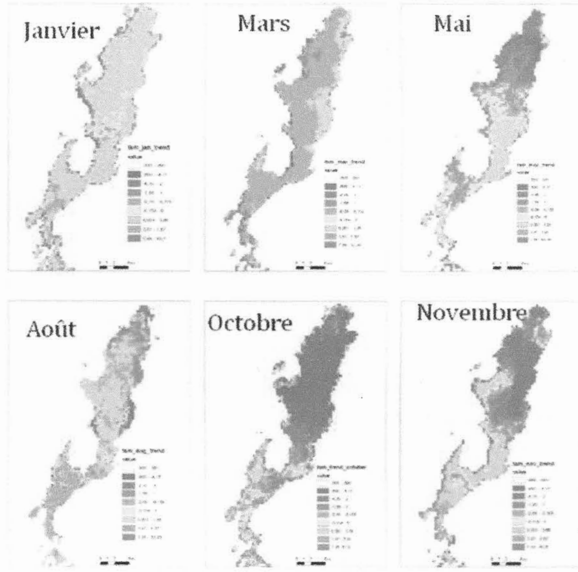

Figure 3 – Cartographie MERIS du trend mensuel des teneurs en matières en suspension (TSM) pour la période 2003-2010

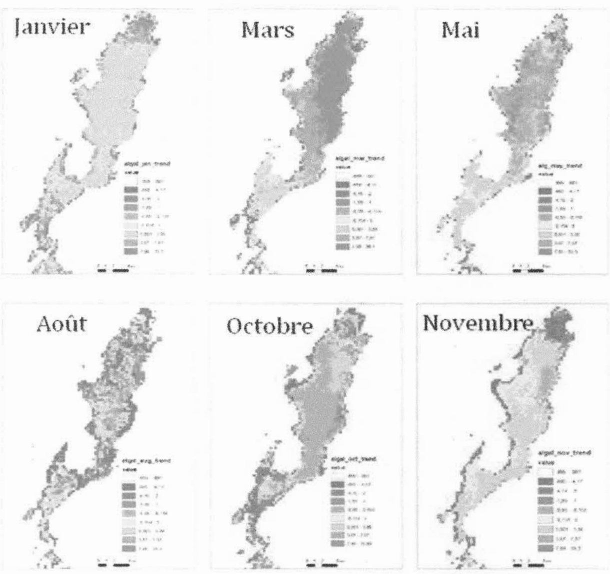

Fig. 2 – Cartographie MERIS du trend mensuel des teneurs en chlorophylle (Chl-a) pour la période 2003-2010

Figure 4 – Radiomètres TRIOS RAMSES pour la mesure in-situ des paramètres de qualité de l'eau (Acquis grâce à la subvention PAES/UEMOA)
1- Radiomètre hyperspectral TRIOS RAMSES-ARC (320 – 950 nm) ; 2- Capteur microFlu-Chl-a à fluorescence ; 3- Capteur microFlu-CDOM à fluorescence ; 4- Appareil de calibration spectrale de terrain

ANALYSIS OF MERIS DATA FOR ASSESSING THE WATER QUALITY IN LAKE GUIERS (SENEGAL): PRELIMINARY RESULTS

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ABSTRACT

Moderate resolution imaging spectro-radiometer (MERIS) 1b image products acquired on April, 27, 2007 were used to run the FUB algorithm for CHL-a, SPM and CDOM concentrations retrieval of Lake Guiers waters. These parameters were found to be in the range: 30 -117 µg CHl-a L^{-1} (mean: 62.13 µg CHl-a L^{-1}); 0.10 - 29.0 mg SPM L^{-1} (mean: 22.01 mg SPM L^{-1}); and 1.10 - 1.90 CDOM m^{-1} (mean: 1.33 m^{-1}). It was not possible to fully assess the detection accuracy of these results due to insufficient or lacking ground truths. Nonetheless, the results show CHL-a and SPM concentrations that compare well with in-situ data from early studies, suggesting (i) the capability of this technique as a low-cost tool for lakes water quality monitoring, and (ii) the reliability as well as accuracy of the method upon the availability of in-situ data for validation.

1. INTRODUCTION

The role of satellite image remote sensing for surface water quality mapping and application in lakes water quality monitoring have received increased attentions over the past few years **[1,2,3]**. Basically, the technique relies on analyzing the spectral characteristics of solar radiations reflected by the water body under consideration, which relate to the "*optical properties*" of the constituents present in the water. However, the reflected energy reaching the satellite sensor [so-called "*water-leaving radiance*" or "*Top-Of-Atmosphere – TOA- radiance*"] is a function of several factors including the spectral properties of the investigated water, its environment (e.g., adjacency effect and sub-pixel contamination), the sensor spectral band, viewing and solar angles, and prevailing atmospheric characteristics. As a result, various problems may arise during interpretation of satellite image data. Hence, for accurate interpretation, the image data should be corrected for all possible potential effects of atmospheric interactions.

With the arrival of a new satellite sensors generation, research devoted to building up original algorithms appropriate for correcting and converting the "TOA-radiance" into *"water-leaving reflectance"* and to derive afterward water quality parameter (WQP) values from satellites imagery have improved greatly **[4,5]**. Algorithms are now available that can be used for retrieval concentrations of individual substances found in lake waters, such as chlorophyll-a [referred to as an index for phytoplankton biomass/development], total suspended particulate matter [taken as the dry weight of all suspended inorganic particles] and coloured fraction of dissolved organic matters [also called *"yellow substances"*]. Such standard algorithms (retrieval techniques used for converting the *TOA*-signal into physical values) are described in several publications **[e.g., 6,7]**.

Based on the above background, this study presents the results of FUB algorithm **[8]** from a full resolution MERIS 1b image product for concentrations retrieval of chlorophyll-a (CHL-a), suspended particulate matter (SPM) and coloured dissolved organic matter (CDOM) in Lake Guiers waters. Its purpose is primarily reconnaissance on the feasibility of remote sensing data as a tool for operational water quality monitoring of Lake Guiers waters. Due to lack of coincident field measurements needed for validation, data compiled from literature were used for tentative validation of the image study results. The results presented here are part of a research project aimed at developing a remote sensing approach towards the implementation of methodical decision-making and management tools for monitoring of the water quality in Lake Guiers.

2. STUDY AREA

2.1 Field Site Description

The investigation area Lake Guiers, is located on the left bank of the Senegal River, to the north of Senegal, about 300 km NE of the capital city, Dakar **(Fig. 1)**. It is a small lake bottoming at -2m below sea level and having an average depth of about 2 m. Its waters stem from Senegal River. At its highest water level (+2 m above sea level), Lake Guiers may expand to cover a surface area of about 320 km^2, measuring up to 50 km from north to south and 7 km across at its maximum. The surrounding climatic condition are arid, with an average annual precipitation of 350 -500mm/yr

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and a mean annual air temperature of about 26.3°C. The area mostly experiences north-easterly Saharan trade winds (Harmatan); the influence of maritime (westerly) winds is moderate. The mean surface water temperature is around 25°C (max: 30°C, min: 18°C) with daily amplitudes variations rarely exceeding 5°C. Differences in temperatures between the top and bottom water layers are said to be "noticeable" only in the period from December to March and range in the order of up to 4-5°C **[9]**. The oxygen saturation is usually above 60 % according to this author. Under these conditions, the euphotic layer of the lake almost matches the entire water column and thus favours phytoplankton development.

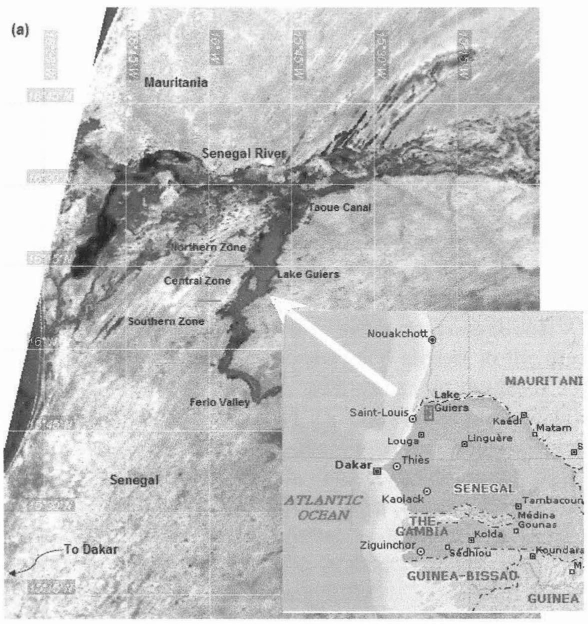

Figure 1: (a) The April, 27th, 2007 MERIS composite image showing the study area (b) Location map showing East to West flow of Senegal River and North to South flow of Lake Guiers).

Lake Guiers is an essential water resource for Senegal. Its main uses are for drinking water, irrigation and fisheries. It accounts for nearly 60% of the daily water consumption of the capital city and its suburbs. Also because of its surrounding fertile soils, irrigation agriculture within the lake catchment is increasingly impacting on the lake water quality, the extent of which is not well documented. According to **[10]**, the new hydrological conditions generated by the regulating dams system (i.e., the stabilization of the lake level at around + 2 m a.s.l. (see **Fig. 2**), and hence permanent softening of the lake water) are ecological factors that were favourable to the expansion of an important aquatic vegetation of free floating and fixed macrophyte (essentially *Typha*, *Phragmites*, *Pistia stratiotes*, *Echinochloa* and *Nymphea*). This proliferation of aquatic seedlings may explain, according to **[11]**, the rapid spread of *schistosomiasis*, which now dangerously affects the health of almost 80% of the population living in lakeside villages. From a geological point of view, the area is covered by sandy sediments of Quaternary and Tertiary (Continental Terminal) age. Aeolian sands accumulate in the form of large SW-NE trending dune systems giving rise to a slightly undulated terrain. The lake bed geology as reported by **[12]** indicates a sediment profile grading from bluish-green silts at the top to fine sands at depth.

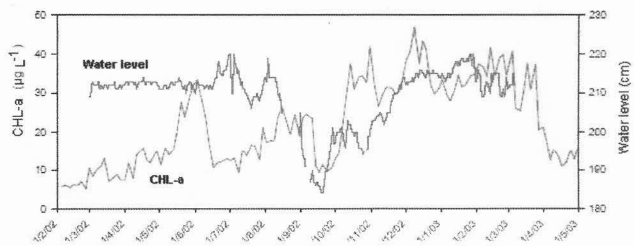

Figure 2: Pattern of variations through time of Lake Guiers CHL-a contents and water level in the observation period February 2002 – May 2003 ***(modified after [13])****.*

2.2 Review of previous studies

There have been to date no attempts to analyse the occurrence of CDOM in Lake Guiers waters while for the CHL-a and SPM concentrations reported in previous investigations of the lake, the following points are worthy of mention:

a) Chlorophyll-a concentrations in range 5 - 45 µg CHL-*a* L^{-1} and 45 - 70 µg CHL-a L^{-1} have been reported **[13,14]**. **Fig. 2** presents the pattern of temporal variations (period February 2002 to May 2003) of CHL-a concentrations at a sampling site located in the Central Zone of the lake (see **Fig. 1** for location). A trend of CHL-a increase can be seen with highest values (30 – 45 µg CHL-*a* L^{-1}) in the period from November 2002 through March 2003. Such a trend has also been observed by **[14]** which reported a similar pattern of increasing CHL-a amounts through the winter months. However, this may not be considered a regular pattern, as evident from comparison of the CHL-a occurrence in the periods of February-April 2002 and February-April 2003. Observations carried out through the years 2002 to 2005 **[9]**, gives report on the occurrence of a high phytoplankton biomass (pluriannual mean = 46 µg CHL-a L^{-1}) that immobilizes most of the nutrients in the lake waters. According to **[9]**, the phytoplankton community is dominated by cyanophytes and chlorophytes with yearly averaged productivity for 2002 to 2005 as 6.5 mg C (mg Chl-a)$^{-1}$ h^{-1}. During this period, the pattern of variability in the CHL-a amount, with

yearly averages of 20 µg Chl-a L^{-1} in 2002, 18 µg Chl-a L^{-1} in 2003, 28 µg Chl-a L^{-1} in 2004 and 51 µg Chl-a L^{-1} in 2005, was observed. Based on the reported wide range of CHL-a values (from 5 to 70 µg CHL-a L^{-1}), it can concluded that Lake Guiers trophic index may vary drastically, almost from oligotrophic to eutrophic state.

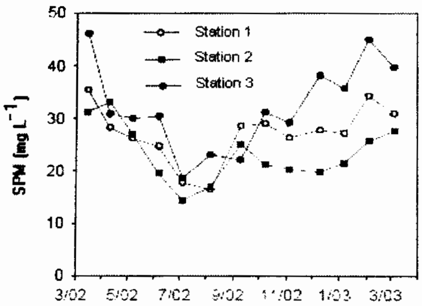

***Figure 3:** Spatial variations of SPM concentrations in Lake Guiers for the observation period March 2002 through March 2003 **(modified after [14])**.*

b) Fig. 3 shows a comparison for the monthly averaged SPM concentrations at three sampling sites located within the central zone. There is some evidence of cyclical variations in the SPM concentrations. On average, SPM concentrations varied almost in the same range at the three stations, with values in range of 15 - 45 mg L^{-1} (mean ≅ 29 mg L^{-1}). The values are lowest in July/August and increase steadily to reach their highest values in February/March. This depicts some highly turbid conditions throughout most times of the year. Also **[15]** reports spatial variation in SPM concentrations along a N-S transect of the lake with SPM values of 3 to 30 mg SPM L^{-1} (mean = 13 mg SPM L^{-1}). The SPM concentrations were lowest in the northern zone (see **Fig. 1**), with values of 3 to 10 mg SPM L^{-1} and increase toward the central zone of the lake, reaching values up to 30 mg SPM L^{-1}. Toward the south, the concentrations decrease again, a situation that can be attributed to the presence of macrophytes vegetation that incidentally decreases the hydrodynamic, thus inducing more particle sedimentation.

3. MODEL AND DATA

3.1 Data Base

The image data used in this study is a full resolution MERIS-1b image product provided by the TIGER project N° 2975 on behalf of ESA. The image was taken on April 27th, 2007 and it was the only cloud free scene covering the study area out of a set of 10 images. **Fig. 1** shows its coverage area. MERIS is a typical nadir looking push-broom imaging system that enables precise monitoring of the Earth's atmosphere and surface. It can be operated either in direct mode (to deliver a full-resolution–FR product of 300m on-ground resolution) or in averaging mode (to produce a reduced resolution-RR product of 1200m on-ground resolution). MERIS measures the reflected solar radiation in 15 programmable bands in the spectral range 412.5-900 nm with an average bandwidth of 10 nm. Further details on the instrument are reported in **[16]**.

3.2 Model

The focus of the methodological approach was to test the usefulness of the FUB/WeW WATER Processor **[8]** for studying Lake Guiers water quality. The FUB/WeW WATER Processor is a plug-in and stand-alone module for the **BEAM** (**B**asic ERS & **E**NVISAT (A)**A**TSR and **M**ERIS) – **VISAT** software developed by Brockmann Consult for **ESA. The BEAM Toolbox** enables viewing and processing of **MERIS, AATSR and ASAR** data products **[17]**. The version employed here is the FUB/WeW WATER Processor 1.01, which can be freely downloaded from: www.brockmann-consult.de\beam.

The FUB model makes use of MERIS products in different bands to retrieve the three WQPs: CHL-a (log scale, µg/L), CDOM (log scale, 1/m) and SPM (log scale, µg/L). Other products derived from FUB include the physical atmospheric properties: aerosol optical depth and water-leaving RS reflectance (see [8] for more details). The retrieval is based on a neural network inversion scheme using the radiative transfer calculations code MOMO (Matrix Operator Method) to simulate the top-of-Atmosphere reflectance (R_{TOA}). Details about this simulation code MOMO and the retrieval algorithm can be found in **[18,19]**. The procedure simply consists of running FUB from within the Beam VISAT software (version 3.7), by selecting the input product file to use [in our case the MERIS product Level-1b image data labelled: "***MER_FR__1PNUPA20070427_111430_000000982057_00352_26959_9717.N1***" and then specifying the output product file name.

During the FUB run, the MERIS product Level-1b image data is "masked" prior to the physical values retrieval generation. This "flagging' gives the range of conditions under which the procedure would provide reasonable results. Once the output file is generated, the retrieval procedure ends with creating a subset product for each output parameter and subsequently anti-logging them to obtain pixel values in standard concentration units, using the band arithmetic expression:

[Subset of WQP output in standard units] = 10^ [Subset of WQP output in log scale units].

Surface water quality mapping based on this technique typically represents sampling on a 300m X 300m pixel grid basis as the smallest unit area. Each grid cell (pixel) is assigned a parameter value averaged over its area while running the algorithm.

4. RESULTS AND DISCUSSION

Tab. 1 presents the summary statistics of the pixel values for the three analyzed parameters, while **Fig. 4** shows their frequency distributions (FD) along with fitted normal distribution model curves N[μ, σ], wherein the symbols μ and σ represent, respectively, the mean and standard deviation of a given parameter.

4.1 Statistical Summary

As shown in **Tab. 1**, the respective mean, median and mode for SPM, CDOM and CHL-a are close enough as to reasonably corroborate the standard assumption of normal distribution. Moreover, the statistics indicates 95% confidence interval on mean concentration values in extremely narrow ranges (from ±1.1% to ±1.4%), thus suggesting high probability for efficient estimate of the hypothetical "population mean" for each parameter.

Table 1: *Statistical summary of the retrieved concentrations values for the three analyzed WQPs.*

Parameter:	**SPM**	**CDOM**	**CHL-a**
Sample size	1151	1147	877
Mean (Average)	22.03	1.33	62.13
95% conf. int. (mean)	±1.4%	±1.1%,	±1.3%
Median	22.99	1.31	60.54
Mode	22.81	1.29	58.32
Geometric mean	19.79	1.33	60.96
Variance	28.07	0.01	158.85
Standard deviation	5.30	0.11	12.60
Standard error	0.16	0.00	0.43
Minimum	0.17	1.10	32.36
Maximum	28.92	1.88	117.58
Range	28.75	0.77	85.23
Lower quartile	22.18	1.27	55.24
Upper quartile	23.79	1.37	67.20
Skewness	-2.78	1.94	1.28
Coeff. of variation	24.04	8.53	20.29

By weighing the range of mean values reported in **Tab. 1**, the average concentrations of all three WQPs lie above the limits of drinking water regulations, suggesting poor quality waters within the lake compartments. CDOM values have a moderately lower coefficient of variation (8.53%), compared to CHL-a and SPM values (20.3% and 24%, respectively), which can be attributed to the fact that CDOM are miscible constituents and thus may be distributed homogenously within the lake waters. However, CHL-a and SPM constituents are present in the water medium as suspensions and therefore may exhibit higher spatial variability due to the complexity of the lake ecosystem in terms of structure and physiography.

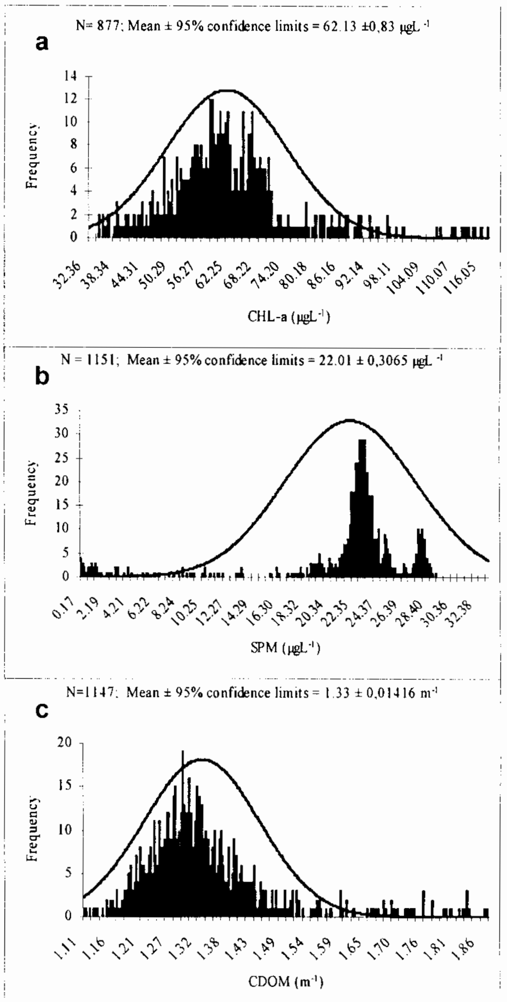

Figure 4: *Frequency histograms with fitted normal distribution curve for (a) CHL-a values (b) SPM values and (c) CDOM values.*

4.2 Comparative Assessment

CHL-a values: At least two major peaks (at around 62 and 72 CHL-a L-1) can be noticed in the FD of CHL-a, which indicate mixed feature or spatial variability of CHL-a. Higher CHL-a values (> 80 µg CHL-a L-1) is interpreted to correspond to chlorophyll pigment production from the floating macrophytes vegetation that typically dominate the phytoplankton communities in shallow zones and near lake shore areas. Moreover, the 95% confidence interval involving the mean for CHL-a from 61.32 to 62.94 CHL-a L^{-1}, is within narrow limits. This means that if the retrieved CHL-a values are averaged to represent standard trophic state at the image acquisition date, the trophic status of Lake Guiers can be deemed "eutrophic" with 95% probability, which is consistent with field observations from early studies **[14,9,13]**.

SPM values: The frequency curve for SPM (**Fig. 4b**) exhibits two dominant peaks (first at about 25 µg/L, and second at about 29 µg/L), which also suggests mixed feature and variability in the turbidity level of the lake water. However, the distribution pattern reveals that SPM values have roughly three population groupings. The fitted normal distribution curve is skewed to the left indicating that most SPM values are "larger" than the mean value of 22.03 µg L^{-1}. This means highly turbid conditions throughout most parts of the lake. This finding is consistent with similar results previously obtained by other investigators (e.g., **[14,15]**). The major factors responsible for the seemingly high turbidity level of the lake presumably are: its shallow depth, the particles input from feeding river runoff water and contribution from Saharan dust storms eruptions as well as the influence of high speed of the Saharan trade winds, which typically induce bottom particle resuspension and particularly active during the period of the year in focus (namely April).

CDOM values: The histogram plot of CDOM values (**Fig. 3c**) indicates a fairly unimodal distribution due to a smaller variance (see **Tab. 1**). Although no available literature data on CDOM concentrations for comparison with the FUB-predicted values, however, the observed lower range of 0.77 m^{-1} (from 1.105 to 1.877 m^{-1}) for CDOM is consistent with similar narrow ranges and order of magnitudes reported in the hydrological literature for CDOM absorption in other lake waters **[20,21]**.

As parts of further data evaluation, the studied WQPs are expressed in terms of co-extant concentrations maps as presented in **Fig. 5**. Visual inspection and assessment of the spatial variability revealed a general westward increase in CHL-a and CDOM concentrations as against the SPM concentrations. High CHL-a and CDOM concentrations and low SPM concentrations in the western shoreline can be attributed to the occurrence of floating macrophytes on the lake reaches. Moreover, it seems that SPM concentrations are higher upstream (near the Mbane village) and downstream of the lake (near the Sear village). Compared to the central zone, these are locations where the lake is shallower and/or narrower; that is, places where the lake hydrodynamic and wind-induced particle resuspension effects may be more important. The spatial variability in the SPM concentrations observable in **Fig. 5c** in the N-S direction of the lake is consistent with the similar one depicted in previous studies [15,9], but may also be interpreted as "bottom reflection effect".

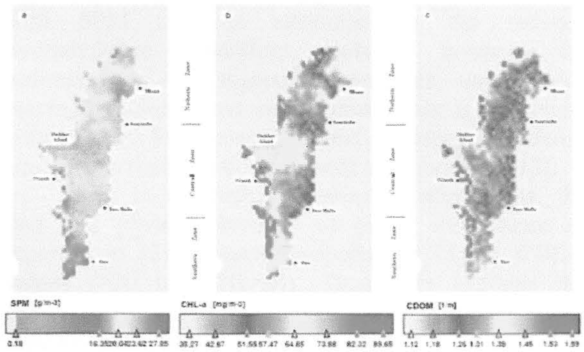

Figure 5: *Spatial distribution of SPM, CHL-a and CDOM concentrations in Lake Guiers waters based on FUB algorithm retrieval from the April, 27, 2007 MERIS observation.*

4.3 Correlation Analysis

Fig. 6 shows a tentative correlation of FUB-predicted with in-situ measured SPM concentrations values complied from **[15]**. With knowledge of the geographic coordinates of the locations of in-situ measured data, it was possible to locate and spatially match-up the measured SPM with the MERIS retrieved values.

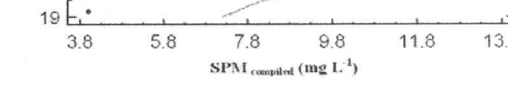

Figure 6: *Plots of FUB-predicted SPM values versus SPM values measured by [15]).*

The correlation coefficient (r) of 0.741 (R^2 = 0.5491) obtained by eliminating an outlier data point is not statistically significant at the 95% confidence level (ANOVA P-value = 0.0567) suggesting a poor or moderate linear relationship between the two data sets. The intercept of about 20 mg L^{-1} for the regression line suggests that, even those points with lower values of measured SPM, contain non-zero levels of SPM. However, nearly 55% of the variance of FUB derived SPM values could be explained by the fitted line, judging from the coefficient of determination R^2. Based on this result, one can nourish the idea that real-case regression equations that may be derived from comparison of FUB retrievals with ground truths could provide a basis for reliable estimates.

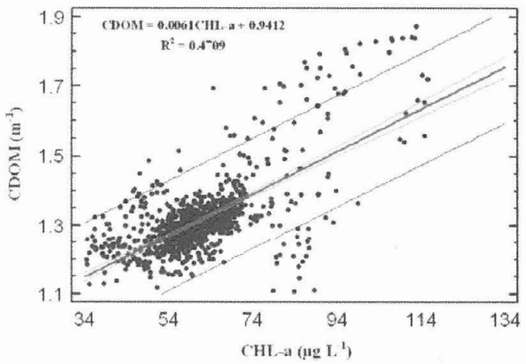

Figure 7: Relationship between CDOM concentration and CHL-a concentration.

Assessment of the possible relationship between CHL-a and CDOM concentrations as presented in **Fig. 7,** revealed a correlation coefficient (r) of 0.686 (R^2 = 0.4709), which is statistically significant at 0.05 level (ANOVA P-value = 0.0000). This signifies that nearly half of the variance of the CDOM absorption can be explained by the variance of the active phytoplankton biomass. Presumably, the implication is that the degradation of phytoplankton cells within the system accounts for a CDOM proportion of 47%.

However, the remaining 53% proportion of CDOM that cannot be explained by the fitted equation may be related to "*allochthonous*" source, which, in turn, may explain the markedly high CDOM contents in the lake. Other factors, which may influence the CDOM, include natural cycling of elements (through decay of plants) and direct anthropogenic activities such as agricultural practices and wastewater inputs.

Fig. 8 displays the correlation between CHL-a and SPM values with a huge point scattering with respect to the best-fit line (SPM = -0.1729CHL-a +32.059). Obviously, about 18% of the variance of SPM values can be explained by the fitted equation, with a correlation coefficient (r) of 0,425. This poor correlation is statistically significant at the 5% level (ANOVA P-value = 0.0000), suggesting possible negative correlation between CHL-a and SPM values. High CHL-a values (> 70 µg CHL-a L^{-1}) basically outweigh the slope of the fitted regression line. Nonetheless, a closer visual examination of the plot revealed that SPM concentrations are generally found to decrease with increasing CHL-a concentrations under two different scenarios:

a) At higher CHL-a concentrations, which typically indicate chlorophyll pigment production from macrophyte vegetation, the apparent inverse relationship with SPM can be attributed to the reduced hydrodynamic condition, which favours the sedimentation of suspended particles under such macrophyte-dominated subsystems. This is consistent with the low SPM concentrations in places with dense aquatic macrophytes development as reported in **[15].**

b) In macrophyte-dominated subsystems, the fact that phytoplankton is of minor importance as reported in **[21]**, clearly supports the higher CHL-a values (>70 µg CHL-a/l). Thus, this explains the relatively weak positive correlation of the data points with SPM at much lower CHL-a values.

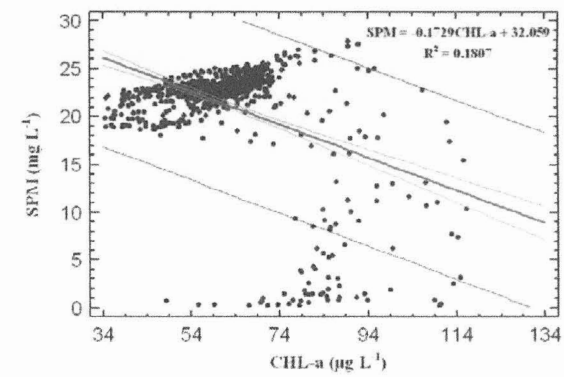

Figure 8: Relationship between SPM concentration and CHL-a concentration.

5. CONCLUSIONS

In this study, the results of running the FUB algorithm **[8]**, an-easy to use MERIS image-based software for retrieving the WQPs CHL-a, TSM and CDOM concentrations were presented. Under the constraints of a lack of ground truths for validation, comparing the FUB-predicted image study results with those from earlier studies revealed good correlation. This supports our hypothesis on the capability of this method to provide reasonably valid estimates for the analyzed WQPs. Nonetheless, an effective assessment of the accuracy of such estimates and certification of the applicability of this procedure for monitoring purposes warrants the need for ground validation programmes, including in-situ measurements of phytoplankton pigment, particulate and dissolved matter, and a field determination of their spectral absorption properties (required as inputs to optical models). Concurrent field measurements of aerosol optical thickness and surface atmospheric pressure (required as inputs for atmospheric model) should also be essential for comparison with the similar MERIS C2R plug-in [22], in order to determine the most preferable and suitable procedure.

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