JEE Journal of Ecological Engineering

Journal of Ecological Engineering 2024, 25(1), 1–16
https://doi.org/10.12911/22998993/169919
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Received: 2023.06.21
Accepted: 2023.08.23
Published: 2023.12.04

Physico-Chemical and Biological Characteristics of the Oum Er Rbia Estuary (North Atlantic Moroccan Coast) – Impact of Urban Wastewater

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ABSTRACT

This study aimed to monitor abiotic factors at three stations in the Oum Er Rbia estuary, not far from the mouth. The stations were situated upstream (S1), in front (S2) and downstream (S3) from the discharge of urban wastewater from the town of Azemmour, which is discharged directly without treatment near the estuary mouth. The selection of these stations appeared appropriate to assessing the quality of the waters, which are influenced by both marine hydrodynamics resulting from very low freshwater inflows and sewage discharges. Monitoring of several parameters, including temperature, pH, dissolved oxygen, conductivity, salinity, turbidity, as well as the content of chlorophyll *a* and pheopigments, enabled the examination of the impact of marine hydrodynamics and the and the specific characteristics of the three surveyed stations. The analyses were performed using R software version 4.2.0. The results obtained indicate that the studied physico-chemical and biological parameters exhibited variations with significant correlations. Statistical approaches allowed the determination of profiles for stations S1, S2 and S3. It is evident that S1 (located slightly far from the discharge) showed a profile that tended to differ from the other two stations, S2 and S3, especially for certain parameters (temperature, pH, turbidity, and chlorophyll *a*). On the other hand, all stations were impacted to some extent by the discharge of wastewater during rising tides. The present study can serve as an assessment tool to support decision-making regarding the physico-chemical quality of the waters of the Oum Er Rbia estuary.

Keywords: Oum Er Rbia estuary, Moroccan North Atlantic coasts, physico-chemical parameters, biological parameters, urban wastewater, marine hydrodynamics, impact.

INTRODUCTION

The paralic areas, in particular, are environments of great ecological, biological, hydrological and economic importance. The Oum Er Rbia estuary has always been the subject of research in several areas, many studies have been conducted in hydrology, geomorphology, sedimentology, etc., (El Khalki 2000; Benabdallaoui et al., 2001; Mhammdi et al., 2005; El Jakani et al., 2019). The Oued Oum Er Rbia basin originates in the Middle Atlas at an altitude of 1800 meters. It crosses the Middle Atlas chain, the Tadla plain, and the coastal Meseta, reaching the Atlantic Ocean through its estuary near the city of Azemmour. The variability of its flow remains linked to precipitation and seasonal variations, as well as to the effect of evapotranspiration (Serbout, 2001). The scarcity of rainfall recorded since the last seasons between 2018 and 2020 has significantly impacted water resources in the Oum Er Rbia basin. Additionally, the development of several barrages at the level of the Oum Er Rbia basin has severely reduced the flow in the estuary, especially after the construction of the Al Massira dam in the late 1970s. This estuary is characterized by the perceptible effect of the Atlantic Ocean, where the water is salty under the dynamic effect of the tide. The Oum Er Rbia estuary is also the place where the force of the river is slowed down, preferentially favoring the sedimentation of several materials. Due to its strategic location, the Oum Er Rbia estuary is threatened by domestic pollution from the city of Azemmour, resulting from the discharge of urban wastewater near the mouth. It is affected by various metal pollutants, as reported in several works (Kaimoussi et al., 1998; Chafik et al., 2000; Cheggour et al., 2005; Asfers et al., 2017). This study was to evaluate the waters quality in the Oum Er Rbia estuary, specifically in the area close to its mouth. Eight physico-chemical and biological parameters were monitored for fifteen months (November 2018–January 2020).

MATERIAL AND METHODS

Selection of stations

The Oum Er Rbia estuary (33°16'N – 8°20'W) is located on the North Atlantic Moroccan coast, 17 km north of El Jadida. It is characterized by tidal dynamics influencing its hydrology. The city of Azemmour occupies the left bank of the river mouth, where the wastewater discharge is open directly into the estuary. Hence, there is interest to focusing our study on this site by monitoring of physico-chemical and biological parameters during the study period.

Three stations were selected upstream of the mouth of the estuary (Figure 1).

- Station 1 – located between two bridges, (S1: 33°17′0.3″N / -8°20′6.11″W), this station is the most influenced by fresh water. It has a mean depth of ~4.90 meters.
- Station 2 – in the immediate proximity of the discharge (S2: 33°17′44.97″N / -8°20′22.45″W), it is subject to a strong discharge of urban wastewater. This station is exposed to adjacent anthropogenic action. It has a mean depth of ~2.25 meters.
- Station 3 – located downstream of the estuary, a little further from the discharge (S3: 33°18′ 10.96″N / -8°20′23.54″W). It is the most directly influenced by marine waters. This station has a mean depth of ~3.8 meters.

Several sampling campaigns were carried out between November 2018 and January 2020, on a monthly basis, during high tide, at the three stations. Measurements were taken for some physico-chemical parameters and on chlorophyll pigments.

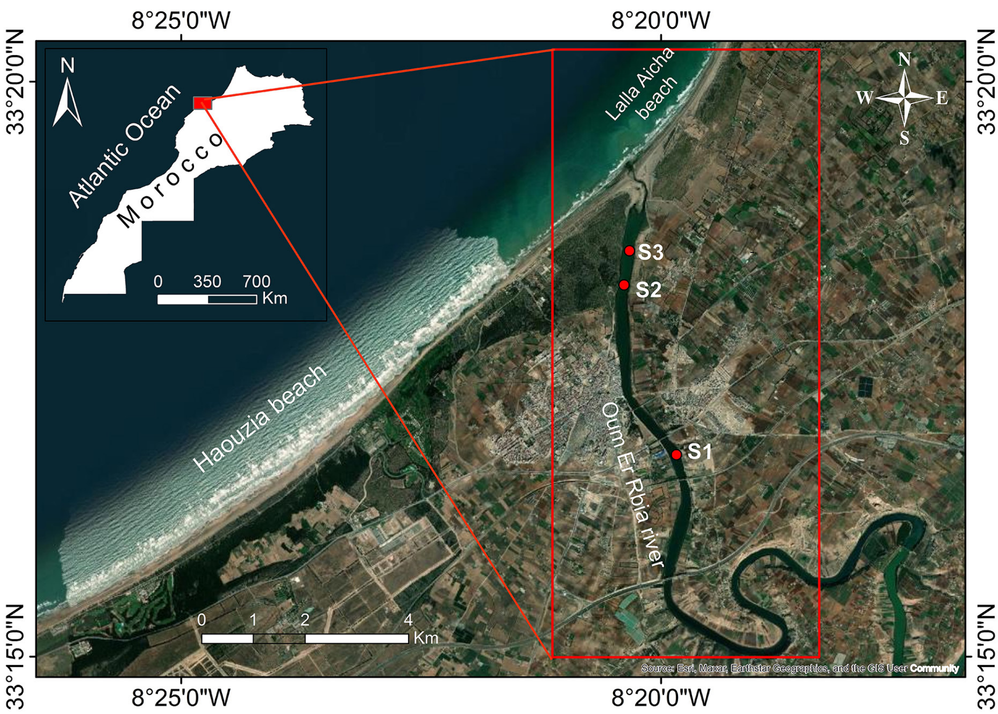

Figure 1. Geographic location of sampling stations (S1, S2 and S3) in the Oum Er Rbia estuary which flows into the Atlantic Ocean at the Azemmour commune

Sampling and analysis

The water samples were collected at the surface and at the shallow of each station from a boat, using a “Niskin, type 1 GO” bottle capacity of 6 liters. Temperature and salinity measurements were taken directly *in situ* by using a multiparameter analyzer (Multi 340i model WTW) coupled with conductivity meter and a pH meter. Turbidity was measured using the Secchi disk with a diameter of 20 cm. The disappearance of the disk was always recorded around solar noon. The concentrations of chlorophyll (*a*) and pheopigments were determined by spectrophotometry using Lorenzen’s equation (1967). Dissolved oxygen was fixed on-site in lapped vials and then titrated in the laboratory using Winkler’s method (1888).

Data processing

The positions of each station and the effect produced by their depth (surface/shallow) were evaluated using the Kruskal-Wallis and Wilcoxon tests. The degree of connection between the collected parameters was evaluated and visualized using a correlation matrix, and correlation heat maps illustrated the correlations through a color chart. The statistical approach was further supported by the principal component analysis (PCA) method, which grouped together the average values of the parameters studied. This exploratory analysis allowed the identification of the number and nature of the main components explaining the existing correlations between the parameters. The level of significance for all statistical tests was set at a p-value < 5%. Graphical representations and data processing were performed using the R Statistical software v 4.1.0 (R Core Team 2020), ggplot2 (Wickham, 2016), ggpubr (Kassambara, 2023), FactoMineR (Lê et al., 2008), factoextra (Kassambara, 2020), GGally (Schloerke et al., 2021), heatmaply (Galili et al., 2018), reshape2 (Wickham, 2020), tidyverse (Wickham et al., 2019), lattice (Team, 2017), gridExtra (Auguie & Antonov 2017) and ggthemes packages (Arnold et al., 2021).

RESULTS AND DISCUSSION

The spatio-temporal comparison of the physico-chemical and biological characteristics of the waters in the Oum Er Rbia estuary was carried out in the three chosen stations (S1, S2 and S3) based on whether the samples were taken at the surface or at the shallow. The profiles are shown in Figure 2. Overall, the spatio-temporal distributions of each descriptor evolve differently according to the seasons.

For temperature, salinity and conductivity, the recordings for each descriptor present parallel trends on the three stations and according to their depth (surface/shallow). The temperature plot shows seasonal variations marked by a rise during the hot season. On the other hand, for chlorophyll (*a*) and pheopigments, the profiles show huge oscillations along the study period and depending on the depth. At station S3 (near the ocean), the readings of these two descriptors deviate from the profiles in S1 and S2, which evolve in parallel with each other. The profiles of the pH and dissolved oxygen recordings show variations according to the seasons and according to the depth.

Physico-chemical parameters

Temperature

The water temperature at the level of the Oum Er Rbia estuary would be influenced mainly by the effect of seawater, and secondarily by the depth and proximity of the domestic discharge. Generally, the waters of the Oum Er Rbia estuary are cool, with temperature ranges of (15.7 and 26.1°C), (14.7 and 24.8°C) and (14.8 and 23.4°C) recorded at stations S1, S2 and S3 respectively. The evolution of the water temperature of the Oum Er Rbia estuary shows well-marked temporal variations, with a cold period extending from November to January, where the minimum temperature is 14.7°C in January 2020 recorded in surface of Station 2, and a warm period that begins in May and continues until September, with maximum temperatures of 26.1°C and 25.7°C recorded in July 2019 at the surface and at the shallow of Station 1 respectively.

The results for this parameter are relatively comparable to those observed by El Khalki (2000) (15 to 26.6°C). A thermal amplitude between 15 to 25.6°C was reported by Al Goh (2022) during a study carried out at the Oualidia lagoon. Joulami (2013) mentioned comparable temperatures between 15 and 26.5°C in the Sidi Moussa lagoon. Furthermore, according to the work of Labbardi (2005), the temperatures, at the level of the Moulay Bousselham lagoon varied at low tide between 12.95 and 30.78°C. At the Togbin lagoon, Chouti

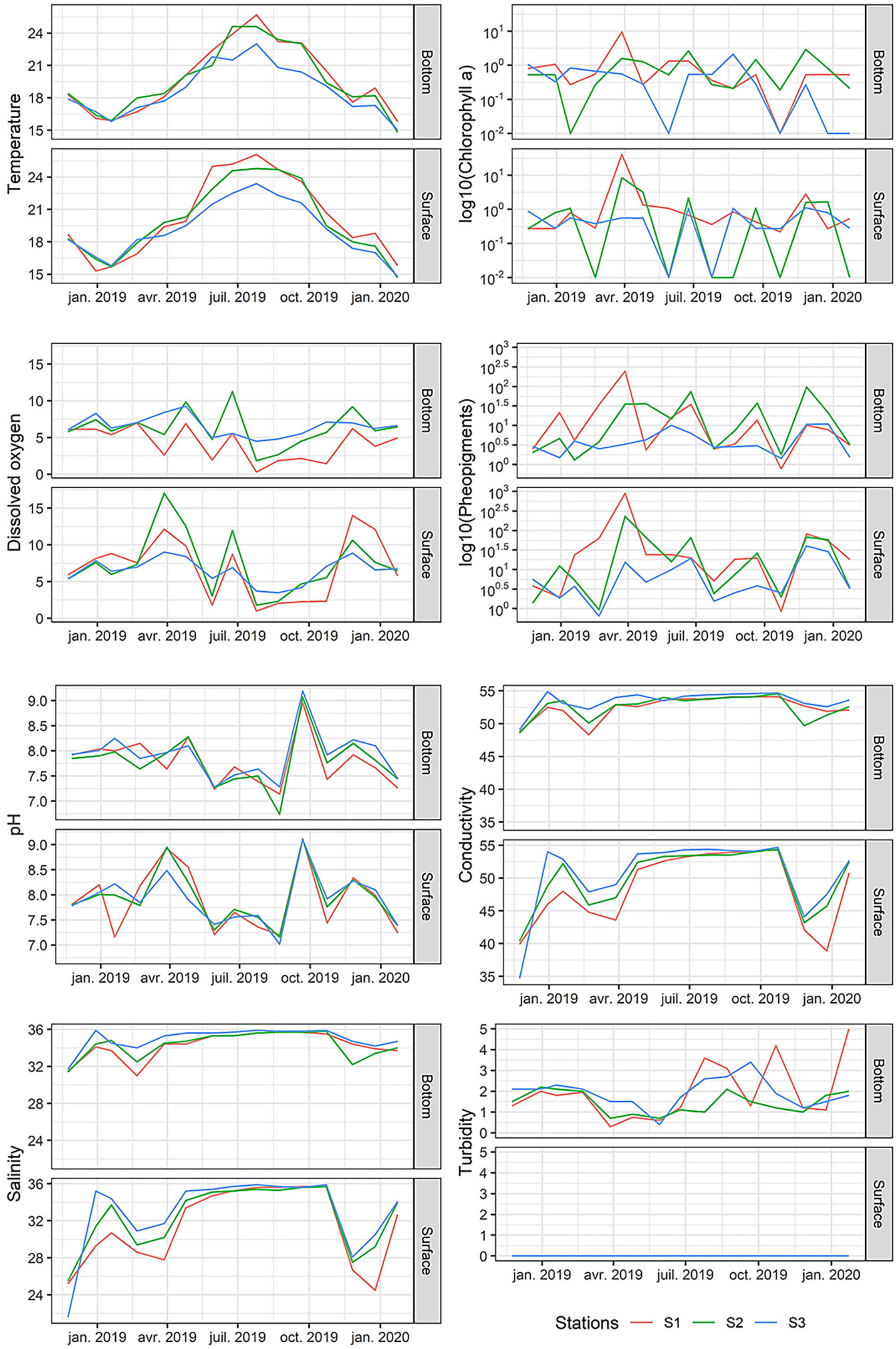

Figure 2. Spatio-temporal variations in physico-chemical and biological parameters in the waters of the Oum Er Rbia estuary at surface and shallow stations S1, S2 and S3: temperature (°C), pH, conductivity (ms/cm), salinity (g/l), dissolved oxygen ($mg.l^{-1}$), turbidity, chlorophyll *a* (µg/l) and pheopigments (µg/l)

recorded higher temperatures with a maximum of 31.7°C and a minimum of 29.8°C (Chouti et al., 2017). Moreover, Izougarhane (2016), mentioned that the temperature of the waters of the Sebou wadi estuary reached 28.2°C.

Conductivity

The electrical conductivity of water is an essential parameter to estimate as it gives an indication of the overall mineralization of water. The conductivity of the waters of the Oum Er Rbia estuary oscillated, with spatio-temporal variations, between 34.7 and 54.9 ms/cm. High values were recorded at the surface and at the shallows, ranging from 54 to 54.9 ms/cm in S3 (November 2018) near the sea. The lowest values (34.7; 38.9 and 39.9 ms /cm) were noted at the surface, respectively in November (2018) in S3, in December and in November (2018) in S1. These results show that the waters of the estuary were highly mineralized during the study period. They differ significantly from the results reported at the Togbin coastal lagoon by Chouti (2017), where the conductivity values ranged between 7.83 and 15.49 ms/cm, and those mentioned by El Morhit (2008) at the Loukkos estuary (0.7 and 42.9 ms/cm).

Turbidity

The turbidity in the Oum Er Rbia estuary proved to be a rather interesting index, with Secchi disc disappearance depths ranging between 0.3 and 5 meters. The maximum turbidity (0.3 m) is observed in March 2019, while the minimum (5 m) is recorded at station S1 in January 2020. In general, in estuaries, turbidity decreases with the arrival of oligotrophic marine waters during the inflow and increases sharply with the arrival of fresh water and suspended solids from the catchment area (El Khalki, 2000). The results of turbidity in the estuary of Oum Er Rbia during the study period would result from the contributions of marine waters, materials brought from the watershed, discharges of urban waters from the city of Azemmour and the proliferation of planktonic species, particularly Dinophyceae. Our results are mostly comparable to those of El Khalki (2000) although his reported a maximum turbidity of 30 cm in the same site.

Dissolved oxygen

During the study period, dissolved oxygen in the Oum Er Rbia estuary underwent many spatio-temporal fluctuations. Overall, the oxygen levels at S1 are intercalated in intervals of 0.29 to 12.15 $mg.l^{-1}$ at the surface and from 0.29 to 6.91 $mg.l^{-1}$ at the shallow of this station, while in S2, the oxygen contents were in even wider ranges ranging from 1.78 to 17.05 $mg.l^{-1}$ at the surface and from 1.78 to 11.25 $mg.l^{-1}$ at the shallow. For S3, the oxygen contents fluctuated between 3.49 and 9.03 $mg.l^{-1}$ at the surface and 4.5 and 9.27 $mg.l^{-1}$ at the shallow.

The highest concentrations were generally displayed in the surface waters of stations S1 and S2. The peaks in dissolved oxygen concentrations (12.15 and 17.05 $mg.l^{-1}$) were noted in the spring (March 2019) in the surface waters of stations S1 and S2. The peak of 17.05 $mg.l^{-1}$ would most likely be linked to the observed bloom of a phytoplankton species *Prorocentrum micans* in March 2019 (Bengriche et al., 2023). Conversely, very low levels were recorded in July (0.99 and 0.29 $mg.l^{-1}$) at S1, simultaneously at the surface and at the bottom. Knowing that for estuarine waters, the minimum recommended dissolved oxygen content is 8.0 $mg.l^{-1}$, the grades recorded at the surveyed stations showed fairly significands variations depending on the season and many fluctuations without any uniformity between surface waters and their shallows.

The work of Benabdellouahad (2006) has shown that the waters of the Bou Regreg estuary are relatively well oxygenated, where the rate of dissolved oxygen reached 12.8 $mg.l^{-1}$ during the stream and even 16 $mg.l^{-1}$ during reflux. El Khalki and Moncef (2007) noted variations between 8.5 and 10.8 mg l^{-1} in the Oum Er Rbia estuary. El Morhit (2008) noted concentrations between 5.21 and 8.06 $mg.l^{-1}$ in the Loukkos estuary. These last results are very similar to ours.

pH

In the Oum Er Rbia estuary, the pH profiles show variations between the three stations compared to each other. The pH values fluctuated between 6.74 and 9.19. The highest values (9.07–9.19) were recorded in September 2019, while the lowest values (6.74–7.28) were noted in August 2019. The contribution of marine waters would have an assured effect on these fluctuations. In general, the results obtained seem comparable to those observed by (Aknaf et al., 2017) at the Marchica lagoon, where the pH varies between 7.96 and 8.9, (Al qoh et al., 2022) at the Oualidia lagoon, where the pH varies between (7.3–8.9) and

Benabdellouahad (2006) at the level of the Bou Regreg estuary, where the pH values are between 7.2 and 8.7 and the works of El Khalki (2000) at the Oum Er Rbia estuary, where pH values are around 8. These results differ from those observed by El Morhit (2008) at the level of the Loukkos estuary, where the values are between 7.43 and 7.8.

Salinity

The study of salinity in estuarine ecosystems, particularly in the Oum Er Rbia estuary, is essential to highlight the effects of marine and continental water contributions, precipitation, as well as the impact of releases from the Sidi Maachou barrage. At the level of the Oum Er Rbia estuary, salinity profiles showed significant spatio-temporal variations, with salinity variability between 25.2–35.7 g/l, 25.5–35.8 g/l, and 21.6–35.9 g/l were noted at the level of S1, S2 and S3, respectively. Salinity reached its maximums from 35.7 to 35.9 g/l recorded in October 2019 at all the three stations, and its minimum 21.6 g/l was recorded in November 2018 at station S1 in surface waters. Benabdallaoui (2001) mentioned minimum salinity of 28 g/l in the Oum Er Rbia estuary. Moreover, Al Goh (2022) recorded values ranging from 26.1 to 36.2 g/l in the Oualidia lagoon. However, the results obtained at the Oum Er Rbia estuary differ from those of El Khalki (2000), where salinity dropped remarkably to 0.3 g/l. Similarly, Benabdellouahad (2006) noted a minimum salinity of 5.6 g/l in the Bou Regreg estuary, and variations in salinity oscillated between 4.3 to 34.65 g/l in the Loukkos estuary (El Morhit 2008).

In summary, the high salinity values observed in the estuary's waters are likely closely linked to the contributions of the marine waters. These high values may also be the direct consequence of the impact of upstream dam constructions, which have affected the supply of fresh water to the estuary. Additionally, the progressively low rainfall and periods of successive droughts in the study area may have contributed to the increased salinity levels.

Biological parameters

Chlorophyll a

Very low concentrations of phytoplankton chlorophyll *a* were recorded at all the three stations, both all the surface and in the shallows. However, three significant peaks were observed simultaneously in March 2019, with elevated values of 40.94 µg/l and 9.61 µg/l reported in station S1 at the surface and at the shallow, respectively. The third high peak, at 8,54 µg/l, was recorded in the surface waters of S2. These recordings occurred following the phytoplankton bloom of *Prorocentrum micans* species in March 2019, which had a density of 14.11×10^7 cell/l in S1 (Bengriche et al., 2023).

These results are comparable to those recorded in the Sidi Moussa lagoon, with values ranging between 6.75 and 67.76 (Joulami et al., 2013). However, they differ from those of El Khalki (2000), who reported chlorophyll *a* values between 0.63 and 13.38 µg/l in the waters of the Oum Er Rbia estuary.

Pheopigments

During the study period, the concentrations of pheopigments recorded oscillated between 0.78 to 909.4 µg/l, 0.93 to 231.7 µg/l, and 0.64 to 40.27 µg/l from upstream to downstream, respectively, in the stations S1, S2 and S3. They showed very pronounced temporal variations, with a minimum of 0.64 µg/l recorded at S3 in February 2019 and a maximum of 909.4 µg/l recorded at S1 in March 2019. The elevated values, recorded at the surface and in the shallow of S1 (909.4–247.35 µg/l) in March 2019 and at the surface of S2 (231.7 µg/l), could be the consequence of a significant degradation of the algal biomass in these two stations. These results remain comparable to those reported in the Sidi Moussa lagoon (Joulami et al., 2013).

Statistical approaches

The Kruskal-Wallis test, based on ranking, was used to note the existence or not of a statistically significant differences between the medians of the parameters of the three stations without assuming that they follow the normal distribution.

According to the principle of this test, if the p-value is higher than the significance level ($p > 0.05$), the null hypothesis cannot be rejected because the test is not significant. This is the case for temperature, pH and turbidity at all three stations regardless of their depth (surface/shallow). The same holds for dissolved oxygen in surface waters (Figure 3). However, if the p-value is < 0.05, we reject the null hypothesis. This is evident for dissolved oxygen content between S1 and S3 shallow waters, with a statistically highly significant p-value (p = 0.0066). Oxygen depletion in the bottom waters in S1, which can even lead to hypoxia (Figure 3), could be caused by the decomposition and stratification of accumulated organic matter produced by phytoplankton or other algal communities during the seasons. Meanwhile, the oxygen content of the water sampled at the bottom of S3, near the mouth, would be directly influenced by the marine hydrodynamics. This would explain the statistically significant difference between the dissolved oxygen content at the bottom of S1 and S3 (Figure 3).

The Kruskal-Wallis test returns statistically significant p-values (p = 0.034 and p = 0.025) for salinity and conductivity respectively, justifying the existence of a difference between the surface waters of the two stations S1 and S3 (Figure 4). The observed distance between S1 (upstream of the discharge) and S3 (downstream and near the mouth) could partly explain this difference.

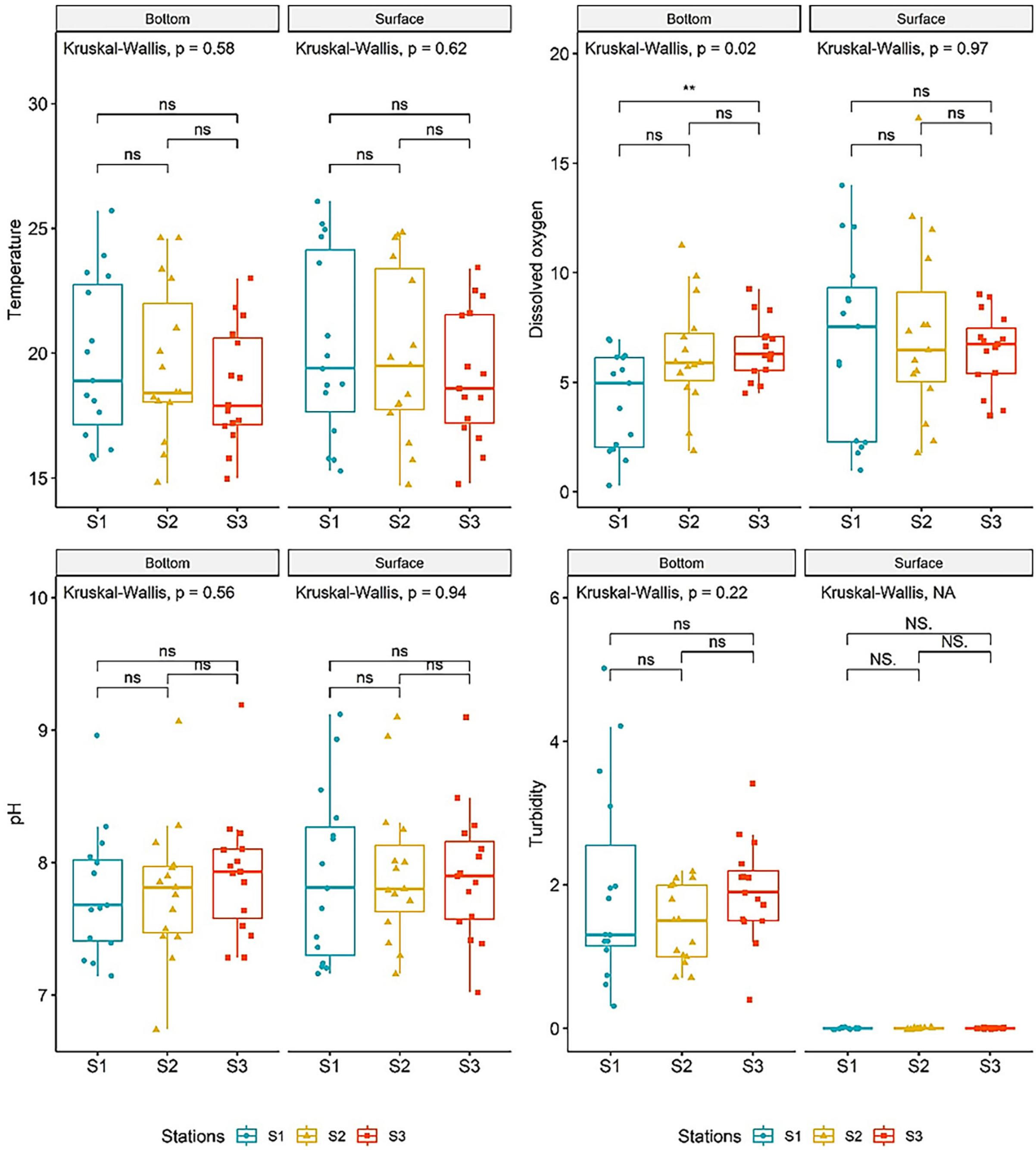

Figure 3. Boxplots comparing of physico-chemical parameters of the waters of the Oum Er Rbia estuary at different stations (S1, S2 and S3) and their depths (surface/bottom): temperature (°C), pH, dissolved oxygen (mg.l[-1]), turbidity, *: significance level; ns: not significant; bottom = shallow

Additionally, for dissolved oxygen, salinity, and conductivity of shallow waters, as well as pheopigments in surface waters. For the pheopigments of the waters from the surface of S1 and S3, the test displays a statistically significant p-value ($p = 0.019$) which allows us to conclude that there is at least one different median (Figure 4).

The visualization of the boxplots and the displayed p-values for each parameter allowed us to anticipate that the profiles of station S3 differ from the profiles of the other two stations (S1 and S2), notably for certain parameters such as temperature, pH, turbidity, and chlorophyll *a*. On the other hand, the Kruskal-Wallis test did not show any significant variance between the medians of the parameters of the three stations when comparing physico-chemical and biological parameters between stations S1 and S2. These stations must be simultaneously impacted by the discharge due to their promiscuity (Figure 4).

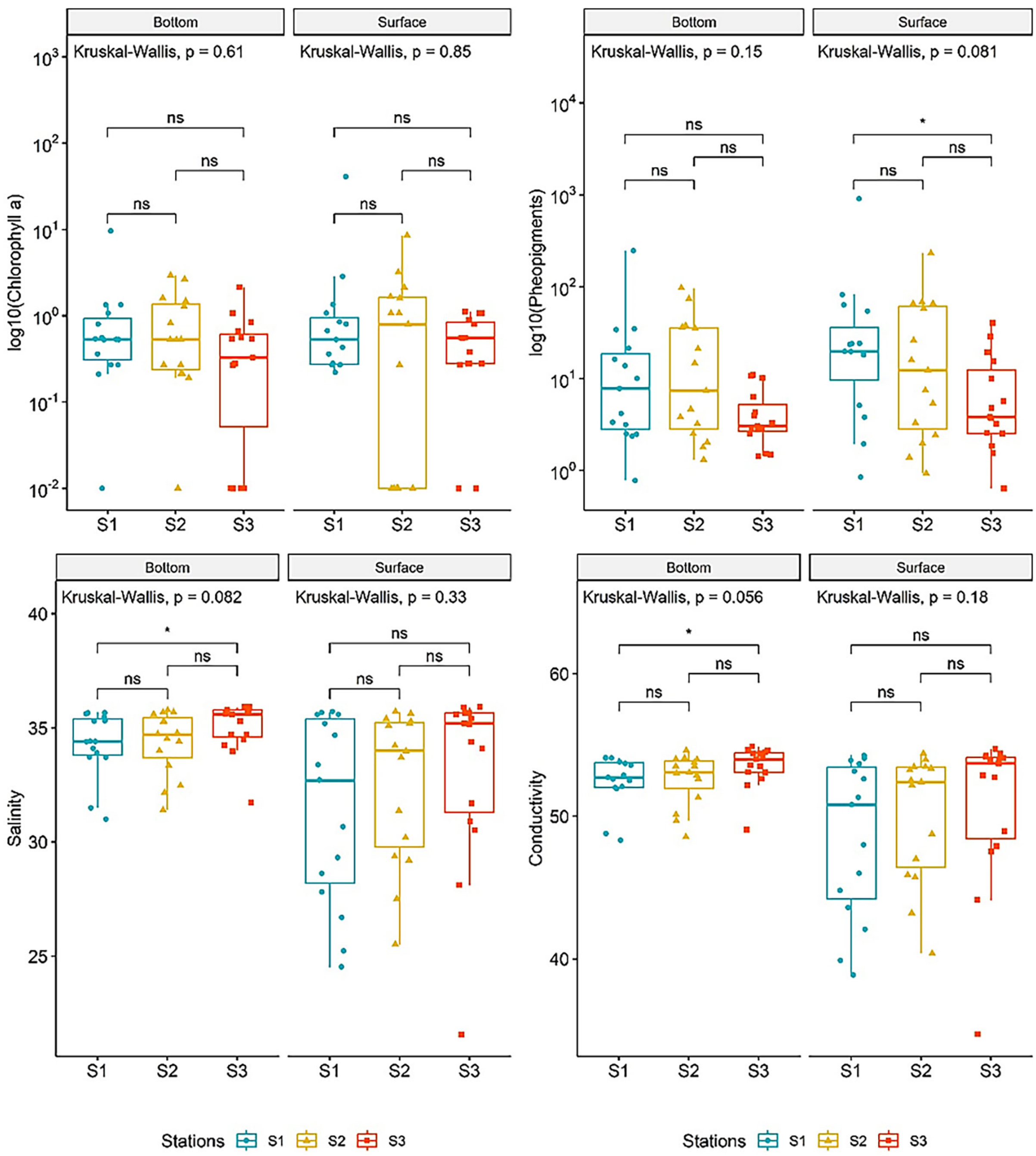

Figure 4. Boxplots comparing physico-chemical and biological parameters of estuarine waters at stations S1, S2, and S3 and their depths (surface/bottom): conductivity (ms/cm), salinity (g/l), chlorophyll *a* (µg/l), pheopigments (µg/l), *: significance level; ns: not significant; bottom = shallow

To properly explore the data, a correlation matrix was created for the quantitative variables: temperature (Tem), pH, dissolved oxygen (O_2), salinity (Sal), conductivity (Cond), turbidity (Tur), chlorophyll *a* (Chl a) and pheopigments (Pheo). This matrix allowed us to visualize the distribution of the variables and their correlation jointly. The existing correlations between the different physico-chemical and biological variables of the waters of the Oum Er Rbia estuary are represented by the correlation matrix, enabling the visualization of the most correlated variables (Figure 5).

Clearly, a strong correlation is observed between salinity and conductivity, with a very highly significant correlation coefficient ($p = 2.23e^{-5}$). We also find a statistically significant positive correlation between temperature and salinity ($p = 0.040$). Similarly, there is a correlation between pH and dissolved oxygen with a coefficient ($r = 0.40$) and statistically significant ($p = 0.04$). Pheopigments show a high correlation with chlorophyll *a* ($p = 4.71e^{-5}$). However, turbidity does not exhibit a statistically significant correlation with chlorophyll *a* nor with pheopigments. Furthermore, a negative correlation is observed between temperature and dissolved oxygen ($p = 0.045$) with a correlation coefficient ($r = -0.39$). This negative correlation can be explained by the fact that oxygen dissolves more easily in cold waters than in warm waters, which act as better solvents for oxygen. It is likely that the increase in temperature stimulates the metabolism of plankton and aquatic animals, leading to a higher oxygen demand and consequently, a decrease in the concentration of dissolved oxygen in the water. A statistically significant negative correlation is also found between salinity and dissolved oxygen ($p = 0.027$) with a correlation coefficient ($r = - 0.43$). Additionally, there is a significantly negative correlation between conductivity and dissolved oxygen ($p = 0.033$) with a correlation coefficient ($r = - 0.41$).

The principal component analysis (PCA) transforms correlated variables into new variables that are decorrelated from each other. The principle is to retain only the first n vectors resulting from the diagonalization of the correlation matrix. The matrix focused on seven variables: Temperature, dissolved oxygen, conductivity, salinity, pH, chlorophyll *a* and pheopigments. The PCA analyses have been conducted separately on the descriptors of the observations of the waters from the surface of the three stations and on those from the corresponding shallows to draw a comparative analysis. The first analysis was performed on the surface waters of the three stations (S1, S2 and S3), which yielded the following

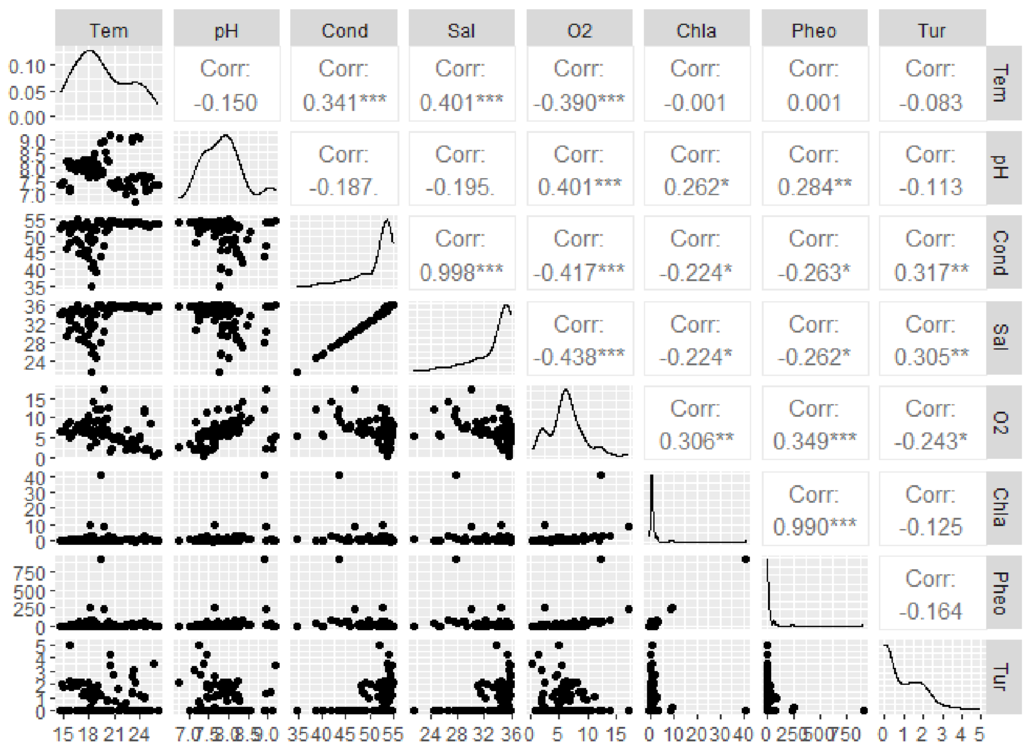

Figure 5. Correlation matrix of quantitative variables in the Oum Er Rbia estuary. Assessment of correlation coefficients and p-values

results (Table 1). The first two axes, F1 and F2, collectively account for approximately 71.8% of the total variance. The highest is observed on the first principal component (46.4%), representing the primary direction along which the parameters vary the most. On the first dimension (F1), conductivity and salinity exhibit a strong negative correlation. Dissolved oxygen shows a positive correlation with F1, though its arrow representation appears shrunk due to information loss in this projection. Nevertheless, as shown in Figure 6, it is evident that the dissolved oxygen concentration in water varies in relation to salinity.

As salinity and conductivity decrease, dissolved oxygen increases, and vice versa. This observation aligns with what was visualized on the correlation matrix. We might interpret F1 as a measure of the oxygen solubility in relation to salinity and conductivity. The second principal component is a linear combination of the variables, independent of the first component, and represents the direction along which the observations show the second greatest variation (25.4%). Chlorophyll (*a*) and pheopigments, which are evidently associated with each other, positively contribute to the construction of this second dimension (Figure 6). F2 could be interpreted as an indicator of primary production activity. The pH, on the other hand, contributed positively to the construction of the F3 axis. We might consider stopping at this third principal component since these three axes retain 84.4% of the information in the data. By including the fourth component, where temperature is positively correlated with the F4 axis, they would collectively explain 94.2% of the variance, which represents a substantial percentage.

From the figure (Figure 7), the profiles of the observations from S1 and S2 seem to exhibit similarities. The profile of the observations from S3 (near the mouth) appears to have a distinct appearance and sometimes even seems to be detached

Table 1. Contribution of variables to the main factorial axes of surface waters in the Oum Er Rbia Estuary

Parameter	Dim.1	Dim.2	Dim.3	Dim.4	Dim.5
Tem	7.67	16.15	6.93	47.50	21.57
pH	9.24	3.76	43.52	27.81	15.65
Cond	18.69	13.77	10.16	8.95	0.03
Sal	19.26	14.55	8.57	6.14	0.003
O_2	16.75	0.004	18.79	3.68	60.62
Chl *a*	13.52	26.59	6.37	3.52	1.64
Pheo	14.86	25.17	5.66	2.43	0.48

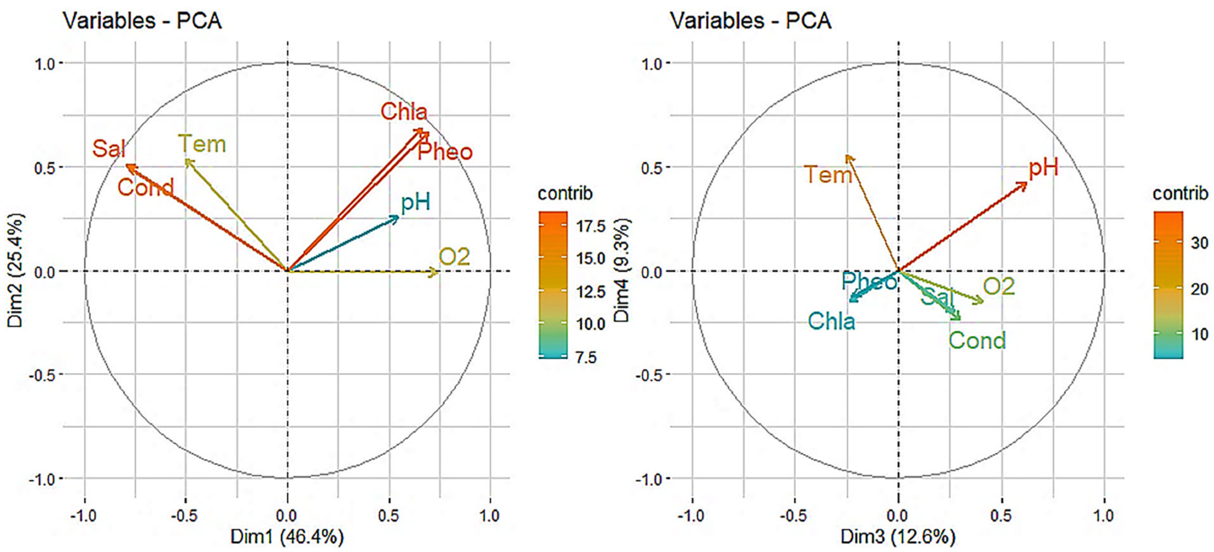

Figure 6. Contribution of physico-chemical and biological parameters to the principal factorial axes of surface waters

from the other two stations. The obtained biplots, regarding the surface waters of the different stations, permitted visualization of how the principal components are related to the original variables. The contribution of each original variable is represented by an arrow. There is a resemblance between the variation patterns for S2 and S3 (located close to each other), but S1 (located far from the other two downstream stations) eventually deviates from them. This statistical approach allowed for reducing the dimensionality in the analysis of the data sets. The first principal component represents the dimension along which there is greater variability in the data. F1 would be interpreted as the dimension that shows the most variation relative to salinity associated with conductivity. On the other hand, some excessively high values of chlorophyll *a* in S2 and S1, detected in March 2019 (40.94 µg/l in S1 and 8.54 µg/l in S2) contributed to the construction of the F2 axis. This signifies that very large data can have a significant effect on the output of a PCA axis. The following principal components represent dimensions with progressively less variation (Figure 8). In parallel, a second PCA was conducted on the parameters and observations of the water from the shallow of the stations (S1, S2 and S3). The contribution of the descriptors to the PCA axes (Table 2) revealed results that are moderately different from those obtained from the surface of the same stations (Table 1). Table 2 and the corresponding Figure 9, illustrating the contributing parameters, reveal that the F1 and F2 axes explain the maximum variation of the observations (64.5%). Salinity and conductivity are the primary contributors to the construction of F1 (36.6%), showing positive correlation, which is in contrast to their rather negative correlation on F1 of the first PCA for surface waters. Chlorophyll (*a*) and pheopigments highly correlated on F2, also make significant positive contributions to its construction (27.9%) (Figure 10).The pH contributes to the third axis, although to a lesser extent, as compared to dissolved oxygen. A satisfactory 81.6% of the variance is retained by the first three components, representing a substantial amount of information contained in the data.

The biplots concerning the waters from the bottom of the three stations (Figure 11) permitted a reduction in dimensionality in the analysis. The first two components show the greatest variability in the grouped observations (in S1, S2, or S3), notably along the F1 axis, where salinity associated

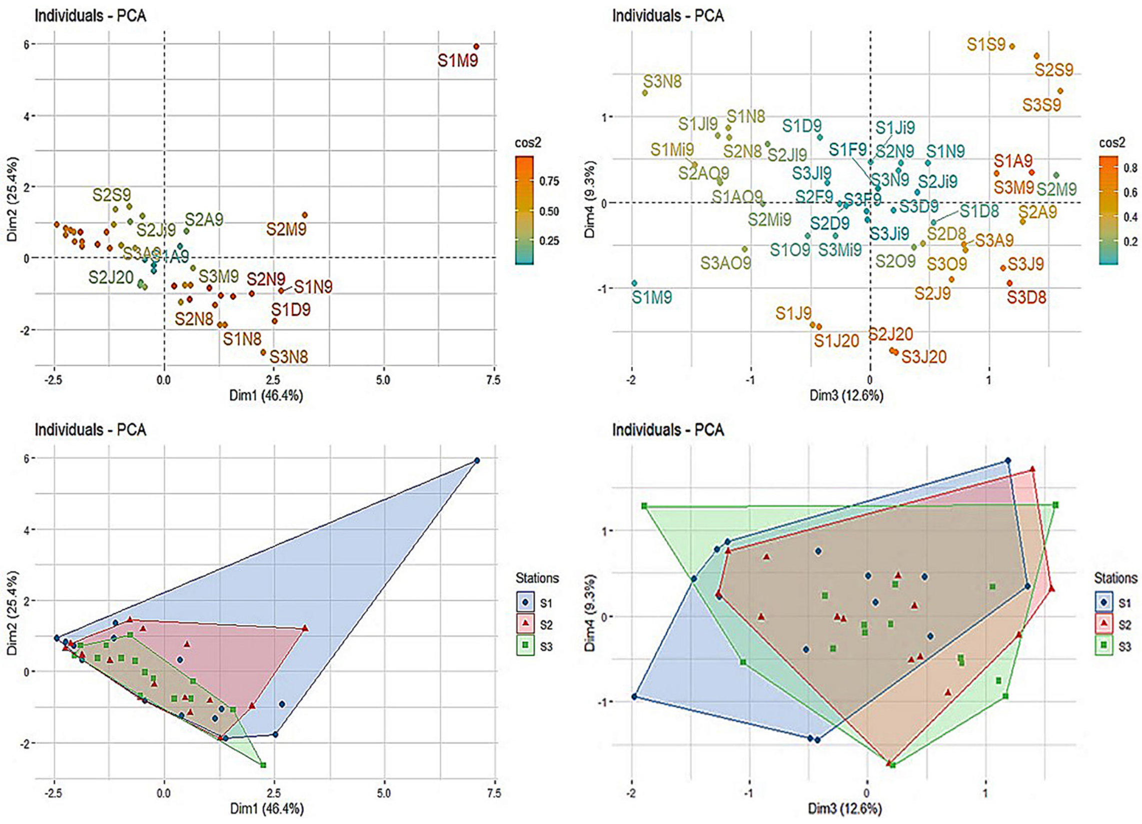

Figure 7. Graph of surface waters observations (S1, S2 and S3) on the four selected dimensions according to their contribution (upper) – grouping of similar observations for each station (S1, S2 and S3) (lower)

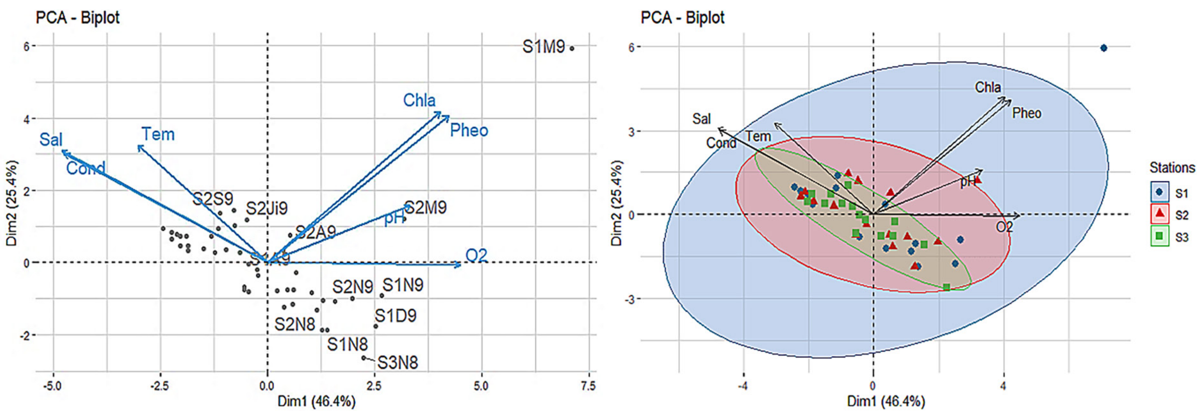

Figure 8. Biplots of surface observations and variables grouped by stations for surface waters

Table 2. Contribution of the principal parameters to the principal factorial axes of the bottom waters (Oum Er Rbia estuary)

Parameter	Dim.1	Dim.2	Dim.3	Dim.4	Dim.5
Tem	19.14	3.08	2.99	18.85	54.72
pH	3.28	0.73	42.45	51.46	2.01
Cond	29.62	0.16	14.56	5.81	3.89
Sal	32.92	0.29	10.65	2.62	0.58
O2	10.9	2.37	27.35	20.75	38.46
Chla	1.79	47.18	0.62	0.37	0.34
Pheo	2.34	46.18	1.36	0.13	0.006

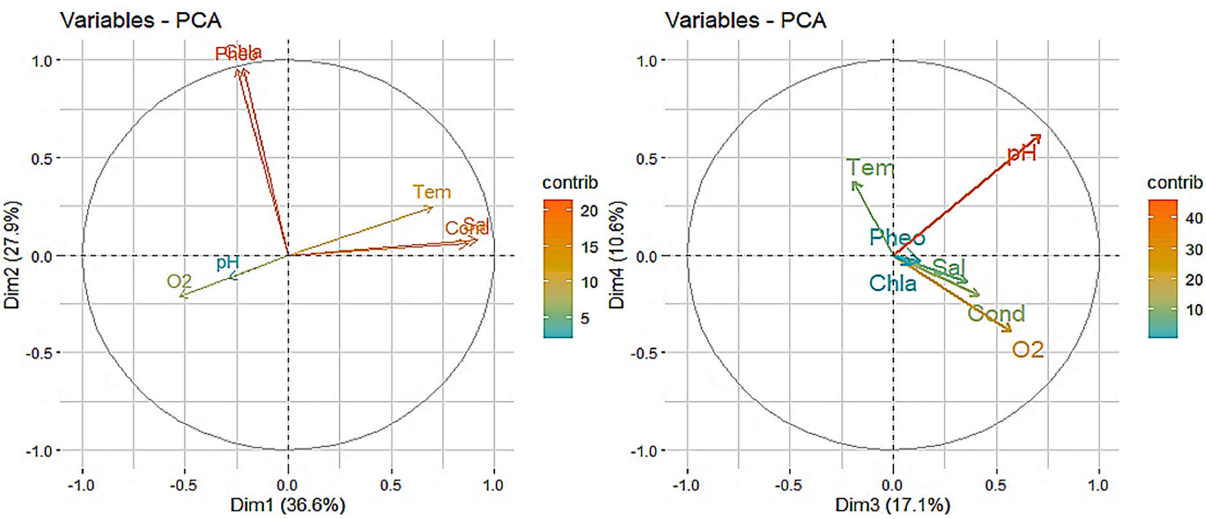

Figure 9. Contribution of physico-chemical and biological parameters to the principal factorial axes of bottom waters

with conductivity and temperature (to a lesser extent) are positively correlated with this dimension. In addition, using correlation heat maps, all the data has been visualized in the form of graphical representations (Figure 12), the data with the correlation heat maps where the values contained in a matrix are represented in the form of colors implying the way in which they are correlated to each other. These representations correspond the correlations to a color chart on a two-dimensional matrix. Thus, the combination has permitted to obtain a visual aspect that is easier to grasp. It should be noted that the results differ from station to station and from surface to shallow. Salinity

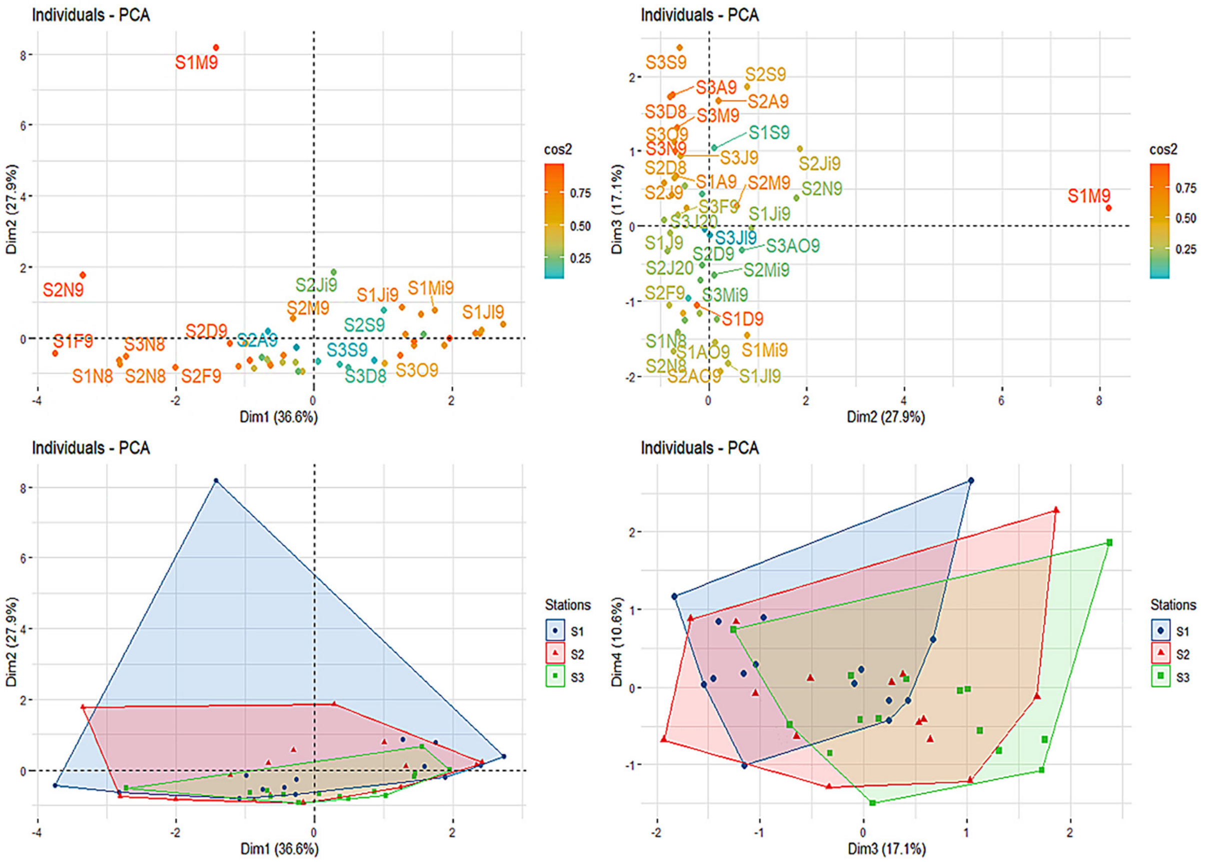

Figure 10. Graph of observations of bottom waters (S1, S2 and S3) on the four selected dimensions according to their contribution (upper) – grouping of similar observations for each station (S1, S2 and S3) (lower)

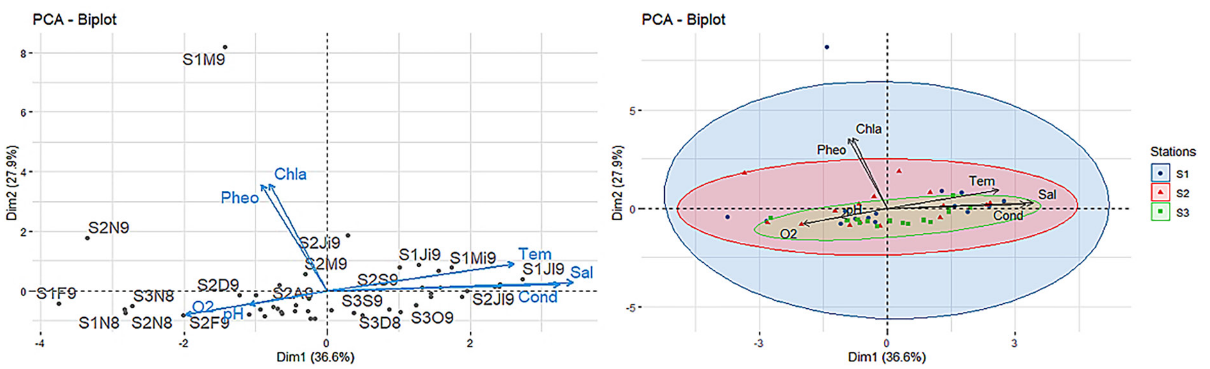

Figure 11. Biplots of observations and variables grouped according to stations for bottom waters

associated with conductivity are positively correlated with temperature for the three stations S1, S2 and S3 at the surface as well as at the bottom constituting a group. The difference resides in the other correlations. For waters at the surface in S1, Chl *a* associated with Pheo are correlated conjointly to pH and then linked to O_2 to form a group of correlated. In S2, Chl *a* associated with Pheo, are correlated first to O_2, and then bind to pH to form a correlated group between them. For S3, Chl *a* are associated with Pheo on the one hand, O_2 and pH are correlated on the other hand, then the two small groups bind to form a group. Other than Cond and Sal, which are associated with each other and correlated with Tem, all other branches reorganize differently according to the level of their correlation to form a group. The links are chained according to the interactions between several descriptors and according to the intensity of the correlation between them.

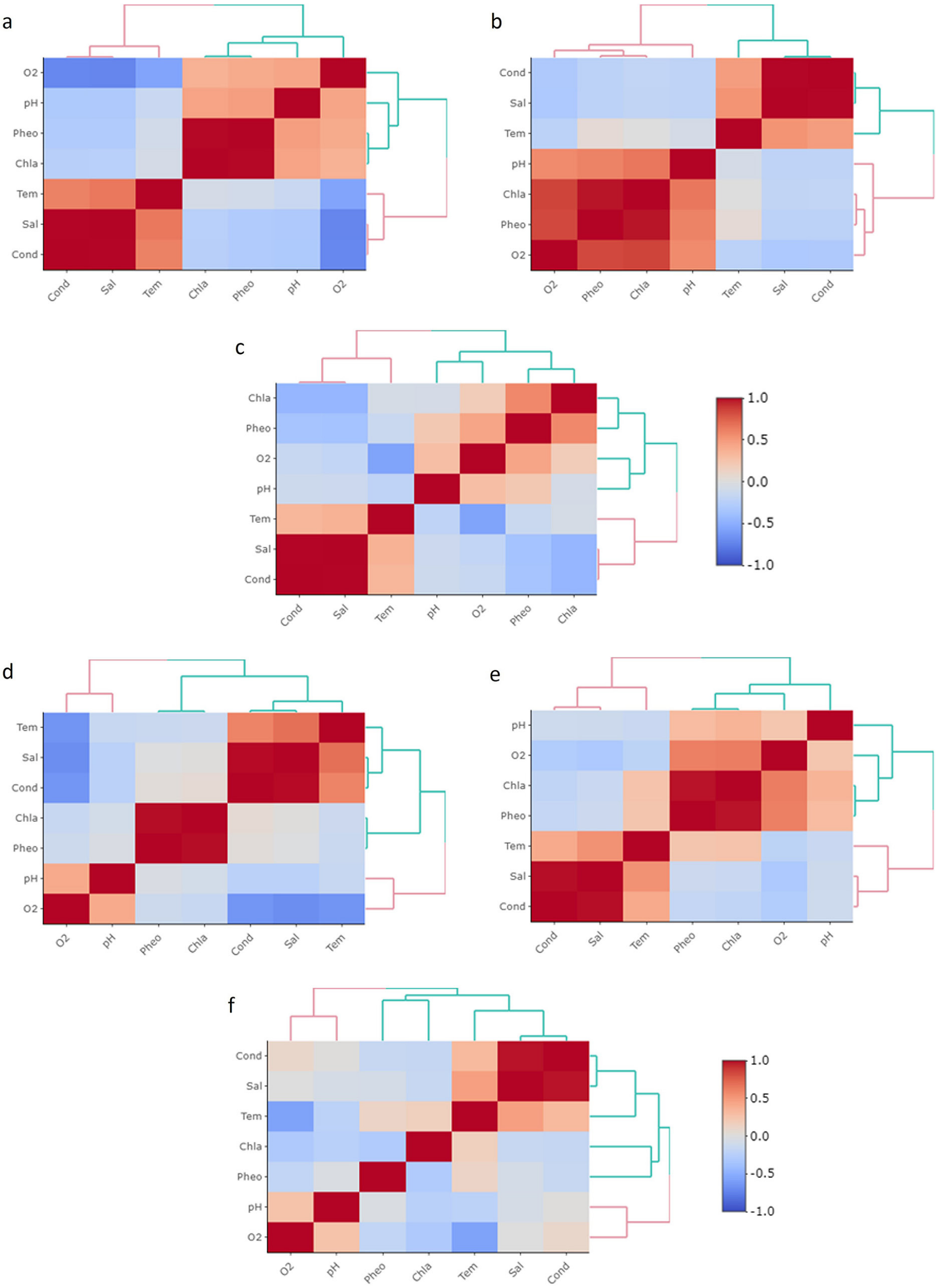

Figure 12. Correlations heat maps of physico-chemical and biological parameters in the Oum Er Rbia estuary: surface waters (a-S1S; b-S2S; c-S3S) and shallow waters (d-S1F; e-S2F; f-S3F) (bottom waters). Positively correlated parameters are indicated in red, and negatively correlated parameters in blue

CONCLUSIONS

The present study was conducted with the aim of establishing a physico-chemical and biological inventory of the waters of the Oum Er Rbia estuarine waters. Monitoring of these descriptors at the three surveyed stations revealed important characteristics. The surface waters were generally transparent, with a few exceptions. Dissolved oxygen showed significant fluctuations, which could be attributed to the combination of several physical factors (temperature, salinity, tidal movements), chemical properties, and biological parameters. At times, these waters could be highly oxygenated, as evidenced by dissolved oxygen levels reaching 17.05 $mg.l^{-1}$ at the surface of S2 in March 2019.

The waters of the estuary were highly mineralized, with conductivity reaching 54.9 ms/cm at the shallow of S3 (near the sea). The three stations recorded very low concentrations of chlorophyll (*a*) with some peaks recorded in the surface waters of S2 (8.54 µg/l) and S1 (40.94 µg/l). According to the Kruskal-Wallis test, the distance detected between S1 (upstream) and S3 (near the mouth) could explain the statistically significant variations detected between the medians of certain water parameters of these stations.Applying PCA to the surface water data from the three stations, approximately 71.8% of the total variance is explained by the first axes (F1 and F2), where F1 (46.4%) represents the principal direction with the maximum variance of salinity associated with conductivity along F1, and on which the data vary negatively in relation to oxygen solubility.

In contrast, PCA applied to the water data from the shallow of the stations shows that the first axes, F1, explain the maximum variation of the observations (64.5%) and F2. The two descriptors, salinity, and conductivity, also contribute significantly to the construction of F1 (36.6%), on which the data are positively correlated, in contrast to their rather negative correlation on F1 of the first PCA for surface waters. The graphs of the observations obtained after PCA also allowed to visualization of the variations, indicating that the data of S2 and S3 appear with more or less similar patterns, while the pattern of S1 appears to be more distinct. However, this last station shows significant overlap with the other two stations. From this observation, we can infer that S3 would receive, in the similar manner, the impact of the discharge during the descending tides.

The heat maps used in this study allowed easy visualization the correlations that occur between the studied descriptors. The results revealed differences from one station to the another and from surface to depth. During the study period, the physico-chemical quality of the Oum Er Rbia estuary waters could not be considered stable either in space or in time. This environment remains subject to tidal movements and strong currents that may be partly responsible for the instability, but they also favor water mixing, which could potentially benefit a rich phytoplankton biomass.

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