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Physico-Chemical and Microbiological Pollution of Industrial Wastewater from Levrier Bay in Mauritania

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ABSTRACT

The objective of this study was to conduct a preliminary assessment of the potential impacts of effluents from freezing plants and fishmeal and oil factories in the Levrier Bay on the aquatic environment through physicochemical and microbiological characterization. Effluent samples from various factories were collected and characterized by pH, dissolved oxygen (DO), electrical conductivity (EC), total dissolved solids (TDS), salinity, temperature (T), phosphate (PO_4), nitrate (NO_3), nitrite (NO_2), biochemical oxygen demand (BOD_5), total coliforms (TC), *Escherichia coli* (EC), and fecal streptococci (FS). The concentration ranges of the effluents were as follows: pH (6.75 to 8.57), DO (1.56 to 4.66 mg/l), EC (26620 to 78520 µS/cm), TDS (13.15 to 38.70 g/l), salinity (16.26 to 49.68 PSU), T (7.67 to 32.7 °C), PO_4 (0.25 to 80.6 mg/l), NO_3 (1.77 to 74.03 mg/l), NO_2 (0.02 to 1.84 mg/l), and BOD_5 (0.5 to 7150 mg/l). TC (2.3×10^3 to 4.6×10^6 CFU/100 ml), EC (50 to 2×10^6 CFU/100 ml), and FS (3.4×10^3 to 2.3×10^7 CFU/100 ml). The evaluated characteristics of these effluents are likely to contaminate and degrade the receiving water bodies (exceeding international standards). Hence, pretreatment of the effluent discharge is indispensable.

Keywords: bacteriology, Levrier Bay, industrial wastewater, physicochemical, pollution, Nouadhibou, Mauritania.

INTRODUCTION

There is no doubt that the fish processing industry uses large amounts of water to clean raw materials and produce by-products. These plants are often located in water-rich areas and often use more water than required to process seafood products (Ben et al., 2007). Water plays a vital and necessary role in all stages of fish and seafood processing including (washing, heat production, sauce preparation, ice production, and more). On the other hand, fishmeal factory wastewater can cause serious pollution problems, especially if not treated properly. They contain large amounts of nitrogen and organic matter, causing eutrophication of water bodies. This phenomenon represents a serious problem caused by industrial outflow (Bhuyar et al., 2021a, 2021b). Direct discharges of industrial wastewater can affect water quality and coastal marine ecosystems (Holmer et al., 2003; Moncada et al., 2019; Quimpo et al., 2020). Recently, approximately 76% of global fish waste is converted into this product (FAO, 2016). However, fishmeal production creates a number of environmental issues related to the discharge of wastewater from operations. Contaminants in fishmeal wastewater originate from specific processes such as heating, pressing, separation, evaporation, drying and grinding (Chowdhury et al., 2010). These treatment stages produce wastewaters that are particularly rich in organic matter, with extremely high total suspended solids (TSS) content, consisting mainly of proteins and lipids (Omil et al., 1996). Natural marine ecosystem is a renewable resources constantly threatened by water resources originating from various anthropogenic activities, which are heavily contaminated primarily by wastewater and industrial discharges (hydrocarbons, gases, heavy metals, etc.), causing marine pollution that affects the physicochemical parameters and microbiological quality characterizing seawater, as well as the functioning of the ecosystem (Bourouache et al., 2019; Zaafrane et al., 2019). The impact of wastewater discharges into the marine environment has long been minimized due to the significant dilution that occurs when wastewater in discharges into the marine environment (Bezama et al., 2012; Ferraciolli et al., 2018; Vallejos et al., 2020). Changes will lead to changes in physical and chemical properties such as water salinity, as well as reductions in oxygen demand of marine species, changes in nutrient concentrations, etc. (Gebauer 2004; Anh et al., 2010, Venugopal and Sasidharan 2020). In Mauritania, several chemical studies were carried out on the contamination status of trace metals in biological tissues, especially in filter-feeding mussels (Sidoumou et al., 1992; Dartige 2006; Legraa 2019; M'Hamada et al., 2011; Wagne et al., 2013) in addition to a study on the physicochemical water quality at the discharge point (Moulaye Ely et al., 2023). The Lévrier Bay is located at the northern end of Mauritania (Figure 1), to the east of the Cape Blanc peninsula. It is roughly oriented north south. The eastern boundary of the bay consists of extensive sebkhas. The western edge corresponds to the Cape Blanc peninsula, featuring rocky formations dominated by sandstone banks. The eastern coast of the peninsula is marked by two smaller bays: Cansado Bay and Etoile Bay (Wagne et al., 2013). Important fishing and industrial activities take place in the Lévrier Bay. It is considered the area with the highest concentration of fishing and industrial activity in the country. It compounds these pressures by owning 32 oil and fishmeal plants among more than 70 fish processing plants for human consumption (Webgate EU 2021). Coastal areas may be severely affected by chemical pollution due to long hydrological residence times and long-term retention of pollutants and atmospheric sediments (Alharbi and El-Sorogy, 2017; Liu et al., 2018; Zhang et al., 2017). Various municipal and industrial wastes are discharged directly into the marine environment without sewage systems. In addition, (Zamel et al., 2010) showed that 75,632 cubic meters of wastewater are discharged into the bay every day, including 3 cubic meters of oily water and 51,755 tons of solid waste, which is a major source of harmful pollution to the bay environment. Cheikh et al. (2020) showed that Levrier Bay suffers from untreated wastewater discharges from fishmeal plants.

No physicochemical and bacteriological studies have been conducted on the raw effluent waters from fish processing plants (freezing and fishmeal and oil production) in the Levrier Bay before.

This study aims to assess the physical, chemical, and biological properties of the raw water effluent from the fishmeal and oil industries, as well as those resulting from freezing fish. In this regard, various parameters (pH, salinity, electrical conductivity, temperature, total dissolved solids, BOD_5, dissolved oxygen, nitrite, phosphate, nitrate, coliforms, fecal streptococci and Escherichia coli) were analyzed to quantify the loads of these waters, which do not undergo any pretreatment before their discharge into the sea. These measures were compared to international standards and similar studies for evaluation.

MATERIALS AND METHODS

Study area presentation

The sampling was conducted in June, August, and September 2023 at six sampling sites, including three sites (S1, S2, S3) located in the Bountiya zone, which houses all fish meal and oil factories, and three sites (S4, S5, and S6) from fish processing and freezing facilities. These sites are scattered across the Levrier Bay (Figure 1) as per the geographic coordinates provided in (Table 1). The selection of these facilities was based on a compromise between accessibility and the potential for water pollution.

None of the six selected sites has ever been used to assess the physicochemical and bacteriological quality of their discharges. The significance of studying this wastewater lies in their direct discharge without any prior treatment.

Sampling

Sample collection was conducted during four campaigns in June, August, September, and November 2023, within six industrial facilities. These included three fish processing and freezing

Table 1. Geographical location and characteristics of the study stations

Stations	Type of activity	Geographic coordinates	
S1	Fishmeal and oil	20°54’46”N	17°01’42”W
S2	Fishmeal and oil	20°54’42”N	17°01’52”W
S3	Fishmeal and oil	20°54’32”N	17°02’13.5”W
S4	Freezing	20°55’08”N	17°02’30”W
S5	Freezing	20°54’22”N	17°02’59”W
S6	Freezing	20°54’11”N	17°03’06”W

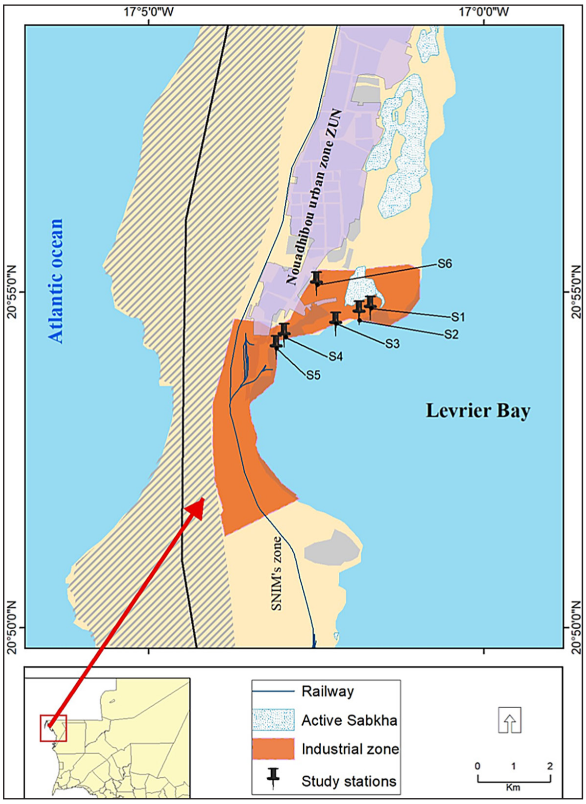

Figure 1. Localization of sample sites

facilities and three fishmeal and oil factories. For physicochemical analysis, the samples were placed in plastic bottles of 500 ml, which had been previously cleaned in baths of acid (HCl, 10%), and then rinsed with distilled water. For microbiological parameters, samples were carefully collected in sterile glass bottles with ground stoppers of 250 ml. These samples were aseptically collected, leaving an air space in the bottle to facilitate the resuspension of microorganisms by agitation before inoculation into appropriate culture media. The samples were stored at 4 °C and transported to the laboratory for analysis. The analyses were conducted at the ONISPA laboratory in Nouadhibou, Mauritania, following the methods outlined in Tables 2 and 3.

The measurement devices used are calibrated before each analysis. Physicochemical parameters were analyzed using the methods presented in Table 2. Microbiological analyses were carried out using the membrane filtration method (0.45 µm). The filters were placed on sterile Petri dishes containing culture media specific to each group of microorganisms. Statistical analysis and graphics have been done using software R 4.2.1.

RESULTS AND DISCUSSION

Physicochemical parameters

The pH is moderately neutral, tending towards alkalinity (Table 4). Dissolved oxygen levels are very low, ranging from 1.65 to 4.66 mg/l. The conductivity values recorded are all above 2.7 mS/cm, which is the maximum permissible

Table 2. Analysis methods for various physicochemical parameters

Parameters	Method
pH, salinity, temperature, electrical conductivity, TDS	Hanna HI9829-01042 multi-parameter (ROMANIA).
Dissolved oxygen	Winkler titration method
Biochemical oxygen demand	OxiTop Box WTW method
Nitrate	Shimadzu high performance liquid chromatography and DR2800 spectrophotometer
Nitrite	Shimadzu high performance liquid chromatography and DR2800 spectrophotometer
Phosphate	Shimadzu high performance liquid chromatography and DR2800 spectrophotometer

Table 3. Analysis methods for various microbiological parameters

Parameters	Culture Medium	Standard
Total coliforms	Chromogenic CAA	ISO 9308-1
Escherichia coli	Chromogenic CAA	ISO 9308-1
Fecal Streptococci	Slanetz and Bartley Agar	ISO 7899-2

for direct discharge into the receiving environment. However, values varied between 26.62 and 78.52 mS/cm for conductivity, with a median of 54.61 mS/cm (Table 4). The median value of TDS was 29,340 mg/l, exceeding the authorized levels. Salinity values ranged from 16.26 to 49.68 PSU, with maximums recorded in September and minimums in August. Water temperatures varied from 7.67 to 32.7 °C, with maximum values recorded at stations S1 and S2 and minimum values at S4 and S6. For nutrient salts, the median value was 18.86 mg/l of nitrates, 0.22 mg/l for nitrites and 6.28 mg/l for phosphate in the samples (Table 4). The extreme values of BOD_5 were 7.150 mgO_2/l and 6.750 mgO_2/l, respectively, recorded in August at stations S2 and S3 (Table 4).

Enterococcus and total coliforms

Bacteriological analyzes of different water samples made it possible to evaluate the contamination levels by station/type of bacteria. Table 5, Figures 2, 3 and 4 present the main results of the microbiological parameters studied. The total coliform results varied between 2.3×10^3 and 8.18×10^8 CFU per 100 ml, and Escherichia coli was found to be abundant at all stations, with the exception of S1 and S6 during all sampling campaigns (Table 5). The average bacterial counts are exceedingly high, with coliforms exhibiting a concentration of 2.7×10^6 CFU per 100 mL, while *E. coli* exhibits a concentration of 5.5×10^5 CFU per 100 ml. All the recorded values exceed the Algerian standard as stipulated in (JORA Decree No. 93-164, 1993).

Streptococci serve as relatively robust indicators of fecal contamination, particularly in environments with high salinity (Gaujous, 1995). Furthermore, they are found to be abundant at station S4 (2.3×10^7 CFU/100 ml, with a minimum value of 3.4×10^3 CFU/100 ml) as depicted in Figure 4. This significantly surpasses the Senegalese standard (SS 05-061, 2001) for direct discharges.

Principal component analysis of physico-chemical parameters across all samples

The conducted principal component analysis (PCA) reveals that 66.8% of the total variance has been explained, with 44.2% accounting for Factorial Axis 1 (F1) and 22.6% for Factorial Axis 2 (F2) (Figure 5). From the analysis of the figure, in the plane formed by Factorial Axes 1 and 2 (F1 and F2), the variables most correlated with Factorial Axis 1 are: nitrite, nitrate, phosphate, BOD_5, pH, EC, TDS, and salinity.

Among the variables examined, the primary contributors to the formation of Factorial Axis 1 can be classified into two distinct groups. The first group encompasses nitrite, nitrate, phosphate, BOD_5, and pH, which exhibit strong positive correlations with each other and with Factorial Axis 1. This is indicative of their alignment along eigenvectors in the same direction. Conversely, the second group consists of salinity, TDS, and EC, which display negative correlations with Factorial Axis 1. Notably, these correlations are notably intensified when these variables are positioned at the

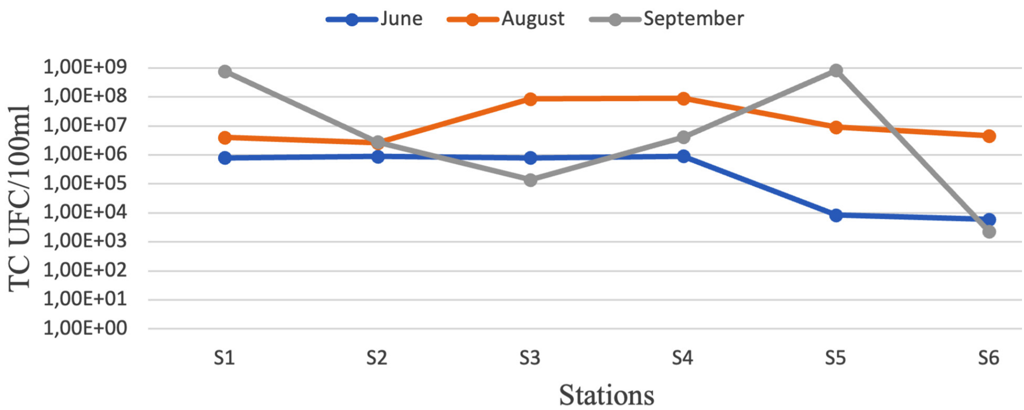

Figure 2. Total coliform levels in the study area during different sampling times

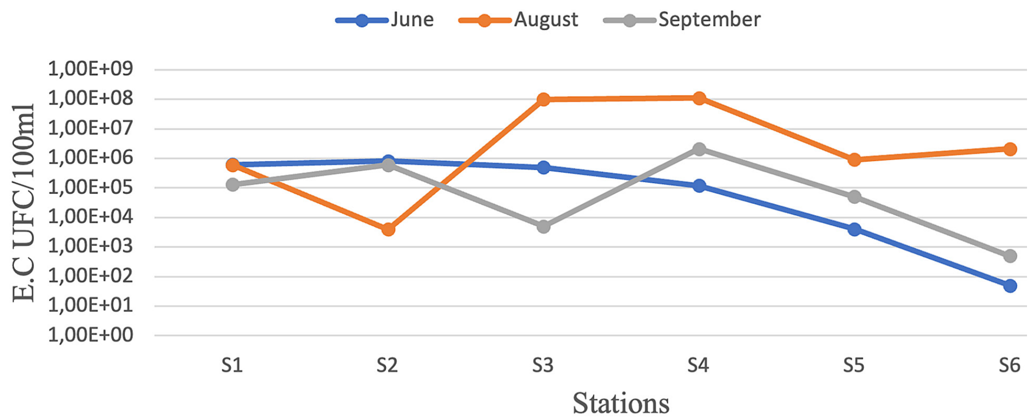

Figure 3. *Escherichia coli* levels in the study area during different sampling times

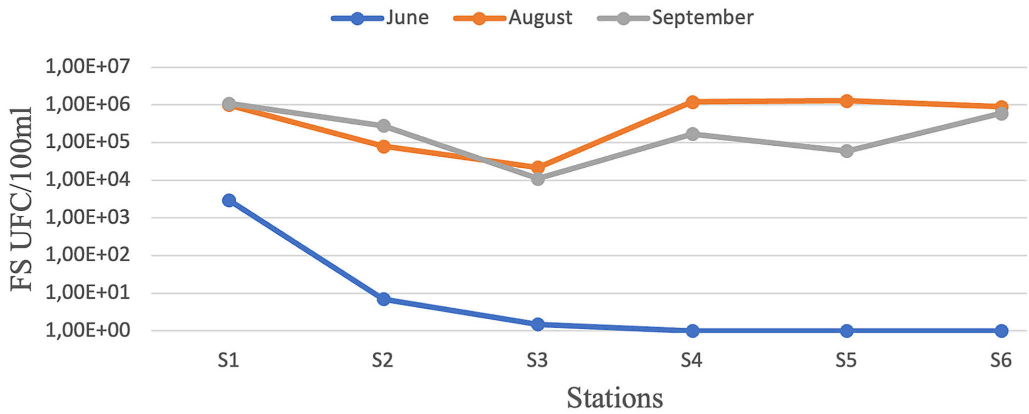

Figure 4. Fecal enterococcus levels in the study area during different sampling times

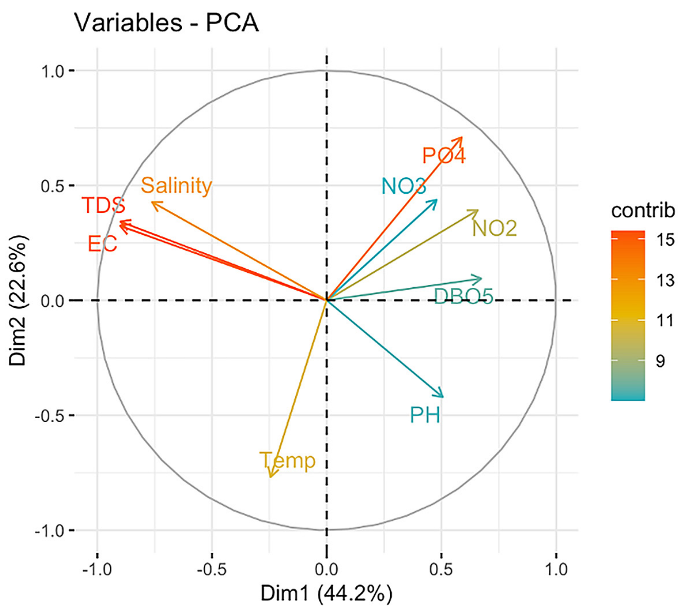

Figure 5. Results from principal component analysis of physicochemical variables – correlation circle between variables (axes 1-2)

extremities of the axis defined by Factorial Axis 1, suggesting a potential common source for these pollutants. On Factorial Axis 2, the variables most strongly correlated with F2 are pH and temperature.

The correlation matrix of the physicochemical parameters assessed in our study is presented in Table 6. Noteworthy Pearson correlation coefficients ($p < 0.05$) are highlighted in bold, revealing

Table 4. Key results of physicochemical variables in raw wastewater from the six stations

Parameters	Min	Max	Mediane	SD	SL
pH	6.75	8.57	7.78	0.521	6.5 - 8.5*
Dissolved oxygen (mg/l)	1.56	4.66	2.19	0.972	>5****
Conductivity (ms/cm)	26.62	78.52	54.61	11.133	2.7**
TDS (g/l)	13.15	38.70	27.33	6.123	-
Salinity	16.26	49.68	35.65	8.618	33-34
Temperature	7.67	32.70	23.01	6.150	30°C*
Nitrite	0.01	1.85	0.22	0.465	5***
Nitrate	1.77	74.03	18.96	25.615	90***
Phosphate	0.25	80.60	6.28	26.244	10***
Biochemical oxygen demand	0.50	7150.00	1280.00	2202.595	100**

Note: * Algerian standard; ** Moroccan standard; *** Tunisian standard; **** WEPA standard; SD – Standard deviation; SL – Standard limits.

Table 5. Key results of microbiological variables in raw wastewater from the six stations compared with the Algerian standard

Parameters	Min	Max	Mediane	SD	SL
Total coliforms	2.30E+03	8.18E+08	2.70E+06	2.55E+08	2000
Escherichia coli	5.00E+01	1.10E+08	5.50E+05	3.38E+07	2000
Fecal Streptococci	1.00E+00	1.30E+06	7.00E+04	4.92E+05	-

Note: SD – Standard deviation, SL – Standard limits.

Table 6. Correlation matrix of physicochemical parameters across all samples

Parameter	pH	DO	EC	TDS	Salinity	T	NO_2	NO_3	PO_4	BOD_5
PH	1.000	-.058	-.466	-.553*	-.364	.102	.323	-.155	.086	.217
DO		1.000	-.171	-.203	-.376	-.225	-.045	-.081	-.087	-.323
EC			1.000	.924*	.876*	.002	-.416	-.315	-.285	-.525*
TDS				1.000	.801*	-.043	-.426	-.278	-.302	-.553*
Salinity					1.000	-.027	-.294	-.180	-.089	-.364
T						1.000	-.362	-.235	-.654*	-.152
NO_2							1.000	.353	.695*	.219
NO_3								1.000	.421	.438
PO_4									1.000	.435
BOD_5										1.000

Note: * The correlation is significant at the 0.05 level.
pH – hydrogen potential, EC – conductivity, TDS – total dissolved solids, T – temperature, NO_2 – nitrite, DO – dissolved oxygen, NO_3 – nitrate, PO_4 – phosphate, BOD_5 – biochemical oxygen demand.

significant associations. A robust positive correlation was observed between electrical conductivity and TDS (0.924), as well as with salinity (0.876). This coherence can be attributed to their shared role as indicators of mineral pollution in wastewater. Furthermore, a substantial positive correlation was identified between salinity and TDS (0.801). Conversely, negative correlations were seen between pH and TDS, BOD_5 and EC, and BOD_5 and TDS. Moreover, phosphate displayed a negative correlation with temperature (Fig. 5).

The pH values are moderately neutral, trending towards alkalinity. The pH values ranged from 6.75 to 8.57, with similar values found by (Ziani et al., 2007) in wastewater from fish processing plants in Agadir. These values could be explained by the use of caustic soda for equipment cleaning or raw material preparation. The quantity and quality of discharged water are also highly variable due to intermittent operations such as washing and rinsing (Benyakhlef et al., 2007).

The pH of the aquatic environment plays a crucial role in the ability of aerobic and anaerobic bacteria to degrade pollutants. Firstly, aerobic bacteria use specific enzymes to break down pollutants into simpler compounds. These enzymes often have optimal activity at a specific pH, typically near neutrality. Secondly, once pollutants are broken down into simpler compounds, aerobic bacteria use these compounds as sources of carbon and energy for their growth and metabolism. An optimal pH promotes the absorption and efficient utilization of these compounds by bacteria, thereby accelerating the degradation process.

The dissolved oxygen levels are notably low, varying from 1.65 to 4.66 mg/l, with a median value of 2.19 mg/l. This can be attributed to high aerobic bacterial contamination in these waters, recording $2.7×10^6$ CFU/100 ml as the median for total coliforms and $5.5×10^5$ CFU/100 ml for *Escherichia coli*. According to (Hamaidi et al., 2009), low levels of water oxygenation can stem from either a heightened consumption of dissolved oxygen by aerobic bacteria during the decomposition of organic matter or a reduced photosynthetic activity among phytoplankton.

Conductivity serves as an indicator of water mineralization extent and offers insights into salinity levels. All recorded conductivity values 26.62 to 78.52 µS/cm with a median of 54.61 µS/cm indicate a high level of inorganic pollution, exceeding the Moroccan standard (MS, 2013), which sets the limit for direct discharge at 2.7 µS/cm. The recorded values indicate excessive water mineralization (Ahoudi et al., 2015). Ziani et al. (2007) found fluctuating values between 3.36 and 96.3 µS/cm in the wastewater of a fish canning factory in Agadir.

The median TDS value was 27.330 mg/l, exceeding authorized levels. This is usually caused by fish remains, scales, internal organs and residues accumulated during the production process, including minerals, organic matter and other uneaten parts, which may be released into the water during processing. fish cleaning and processing process. (Sankpal and Naikwade 2012) found TDS values ranging from 8.200 to 14.700 mg/l in wastewater from a fish processing factory. A high amount of TDS contributes to turbidity and the creation of a barrier that obstructs the penetration of light, thereby significantly decreasing photosynthesis. This phenomenon results in a drop in dissolved oxygen levels, as indicated by the significantly low dissolved oxygen values in these discharges.

Salinity values ranged from 16.26 to 49.68 PSU, with a median of 35.65 PSU. Maximum values were recorded in September, and minimum values were recorded in August. Salinity plays a crucial role in regulating a multitude of physical, chemical, and biological processes in aquatic environments. It can serve as an indicator of seawater intrusion or contamination stemming from wastewater and/or industrial waste sources (Vidya et al., 2020). The salinity values are not very different from those reported by (Moulay Ely et al., 2023), ranging between 13 and 56.4 mg/l.

The temperature values during the study period were always below 30 °C, with slightly higher values at stations S1 and S2 in June and September. The high temperature can be explained by the use of heat by these factories during various stages of flour production, such as cooking, drying, pressing, etc. (Elaouani et al., 2019) found values ranging from 21 to 31 °C in industrial liquid discharges in Agadir.

Nitrites and nitrates recorded values respecting the Tunisian standard (TS, 2018) with medians of 0.22 and 18.86 mg/l respectively. Wastes discharged from fish processing industries are degradable, although they pose a threat to microorganisms in coastal waters. The extent of pollution is moderately high, as shown by the results, but it has no impact on the receiving environment.

Phosphate had a median of 6.28 mg/l. The minimum values varied between 0.25 and 0.29 mg/l in S1 and S3 and 60 and 80.6 mg/l in S4 and S6, confirming the polluted nature attributable to these discharges. The Senegalese standard (SS 05-061, 2001) recommends a phosphate concentration of 10 mg/l. However, the discharges analyzed far exceed this threshold. Excess nutrients in the form of phosphorus and nitrogen in receiving aquatic environments contribute to eutrophication, characterized by excessive growth of algae and aquatic plants. These significantly high concentrations can be attributed to the use of detergents during various washing operations and to incomplete degradation of organic matter (flesh and bones).

BOD_5 values show inequality variations among different plants. This difference varies from 0.5 to 7140 mg/l at sites S5, S3, S6, and S9, respectively. These high BOD_5 concentrations are primarily due to fish residues present in wastewater, as well as blood and viscera. Our results are consistently higher than those of (Salama et al., 2016), ranging from 587.5 to 805.3 mg/l in wastewater collected from the city of El Jadida in Morocco, and (Bourouache et al., 2019), ranging from 983.78 to 1720.14 mg/l in wastewater from the city of Agadir. However, according to (Putra et al., 2020), wastewater from fish flour processing contains 140 g of COD/l, consisting of 60% oil and fat, 27% proteins and 13% of a mixture of soluble organic matter and suspended matter.

In this sense, (Moulaye Ely et al., 2023) recorded BOD_5 values ranging from 396 to 961 mg/l at the discharge points (downstream) of these plants in Nouadhibou with a low or equal to 3 biodegradability index DCO/BOD_5, indicating that they are biodegradable.

CONCLUSIONS

The Levrier Bay is a significant Mauritanian fishing area with a coastline renowned as the world's richest in terms of fishing. Today, this highly important area faces multiple threats related to anthropogenic activities such as urban and industrial discharges. This study provides exclusive information based on bacteriological descriptors (total coliforms, *Escherichia coli*, and fecal streptococci) and physicochemical parameters (pH, electrical conductivity, dissolved oxygen, total dissolved solids, temperature, salinity, phosphate, nitrate, nitrite, and biochemical oxygen demand) of raw wastewater from various evaluated industrial units.

The study yielded the following conclusions: the raw discharges from freezing and fish oil and flour factories are highly contaminated, with conductivity reaching very high values (26.62–78.52 μS/cm), salinity has an average of 37.61 μS/cm. Additionally, phosphate shows moderately high values with an average of 20.27 mg/l. Biochemical oxygen demand and total dissolved solids reached 7.15 mg/l and 38.70 respectively. Overall, the majority of analyzed parameters exhibit values that fail to meet international standards for wastewater, especially dissolved oxygen, conductivity, TDS, salinity, phosphate, and biochemical oxygen demand.

The data generated in this study will undoubtedly help the highest authorities of the country to take urgent measures, including the establishment of a wastewater treatment plant to treat these effluents before discharge. Factories must also adhere to wastewater treatment specifications before discharge to protect and ensure the sustainability of fishery resources.

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