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Spatial evolution of physicochemical and bacteriological water quality at the Mouth of Oued Sebou, Kenitra Province, Morocco

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Abstract

Our study aims to assess the physicochemical and bacteriological quality of water in Oued Sebou. Of particular interest is its significance for domestic and agricultural purposes, as well as the imperative to monitor pollution levels. Downstream of Kenitra city, the compounded effects of urban, industrial, and agricultural activitiesexacerbate environmental degradation annually. We conducted analyses at four sampling stations, strategically positioned both upstream and downstream of discharge points, encompassing two industrial and two urban effluents. Fifteen key physicochemical parameters were scrutinized, including temperature, pH, conductivity, suspended solids, dissolved oxygen, biochemical oxygen demand, chlorides, nitrites, ammonium, nitrates, sulfates, NTK, turbidity, total phosphorus, and iron. Additionally, microbiological parameters such as fecal coliforms and fecal streptococci were examined. Our findings underscore a significant disparity in water quality between upstream and downstream regions, with the latter exhibiting substantial degradation in comparison to established Moroccan standards for surface waterquality.

Keywords: Surface water, Oued Sebou, Bacteriological quality, Physicochemical quality.

Full length article *Corresponding Author*, e-mail: *smslaoui@yahoo.fr* Doi # https://doi.org/10.62877/47-IJCBS-24-25-19-47

1. Introduction

The Sebou basin, covering an area of 40,000 km^2, is located in the northwest of Morocco and remains one of the most important basins in the Kingdom, embodying the backbone of the hydrographic network [1]. It houses one-third of the country's surface water resources. This is where the Oued Sebou originates, emerging from the Middle Atlas and traversing about 500 km before flowing into the Atlantic Ocean near the city of Kenitra. Endowed with a high population density, numerous industrial units, and sustained socio-economic growth, the Sebou basin is subject to various forms of pollution, including domestic, industrial, and agricultural, jeopardizing the development of several sectors in the region [2]. Water is a vital element not only for human health and well-being, but also for animals, plants, and all other living beings [3-4]. Renewable freshwater is an indispensable resource for life, deserving particular attention due to its significant alteration and serious threat by human activities. Indeed, rapid population growth associated with rapid urbanization, causing numerous disturbances to natural environments [5].

Industrialization, and irrational use of fertilizers and pesticides, contribute to an imbalance in ecosystems and generate pollutants that can alter the physicochemical and biological quality of receiving aquatic environments [6-7]. Moreover, they can compromise water uses such as bathing and water abstraction [8]. Morocco experiences unequal distribution, both temporally and spatially, of precipitation and the water resources they generate [9-10]. Due to increasing pressure from water consumption and socio-economic development, these water resources are becoming increasingly limited, resulting in significant scarcity affecting both their quality and quantity [11]. Recent data indicate a worrying increase in pollution levels in the Sebou river, mainly due to untreated industrial and urban discharges. High concentrations of heavy metals and toxic organic compounds threaten the quality of aquatic ecosystems and the health of riparian populations [12]. Faced with this critical situation, measures to protect the Sebou River have been undertaken, including the establishment of stricter regulations on industrial discharges and the improvement of wastewater treatment infrastructure [13]. Thus, the assessment of water quality is of crucial importance to control, preserve, and prevent surface water pollution. A more comprehensive diagnosis of the current pollution situation and an assessment of its evolution are greatly needed to protect this ecosystem. It is in this perspective that our work is framed, aiming to study the impact of anthropogenic and urban activities on the quality of surface waters of the Sebou River, with the aim of protecting human health.

2. Materials and methods

2.1. Presentation of the Study Area

Geographical Framework the Sebou River is one of the most important rivers in Morocco. It originates in the Middle Atlas Mountain range at an altitude of 2030m and flows for 600 km before reaching the Atlantic Ocean (Figure 1). Its watershed, located in the northwest of Morocco between parallels 33° and 35° north latitude and 4°15' and 6°35' west longitude, covers nearly 40,000 km^2. It is bounded to the north by the southern front of the Rif Mountain range, to the south by the Middle Atlas, to the east by the Fes-Taza corridor, and to the west by the Atlantic Ocean.

2.2. Sources of pollution

Annually, a volume of 120 million cubic meters of wastewater, out of the 300 million cubic meters discharged into the entire Moroccan hydrographic network, is discharged into the various tributaries of the Sebou basin. Industrial and urban pollution of the rivers is generated by food and agricultural industries: sugar refineries, oil mills, oleic companies, textile industries (spinning, weaving, garment making), chemical and para-chemical industries (fertilizers, detergents, leather; manufacture of pulp, paper, and cardboard), cellulose industries, paper mills, tanneries, refineries, factories manufacturing chemical and para-chemical products, non-metallic mineral industries, beverage manufacturing companies, mechanical and electrical industries: metal refining, foundries, boiler making, etc. [14-16].

2.3. Sampling

Sampling was carried out taking into account the lithological diversity of the basin, the distribution of anthropogenic activities, and confluence areas. Four sampling stations (P1 to P4) were selected along the Oued Sebou and its tributaries (Figure 2) to reflect the true characteristics of surface waters throughout the study area. Water samples were collected during the dry season (July, August, and September 2023).

2.4. Analytical procedure

The quality of the water samples collected was assessed in accordance with Moroccan standards (Moroccan standards for surface waters, 2002), by measuring their physical, chemical, trace element and bacteriological characteristics. To ensure quality and control of surface water samples, as well as to increase the reliability of data for the analytical procedure, triple analyses were conducted for each parameter during then analysis. During each sampling event, water and air temperature, electrical conductivity, and pH were measured on-site. Water samples were then collected in plastic bottles that had been rinsed with water from the station. They were stored at 4°C during transport to the laboratory and analyzed within 24 hours. The analysis methods followed AFNOR standards and Rodier [17-18]. Chlorides were measured using the Mohr volumetric method in the presence of silver nitrate, while nitrates were determined by the colorimetric method in the presence of sodium salicylate. Chemical oxygen demand was determined using the standardized AFNOR method. Table 1 summarizes the methods as well as the standard used for the analysis of water samples.

2.5. Trace elements

The analysis of trace elements such as lead (Pb), zinc (Zn), copper (Cu), cobalt (Co), cadmium (Cd), nickel (Ni), and chromium (Cr) was conducted using inductively coupled plasma spectroscopy (ICP) with the PerkinElmer ICP-400 emission instrument, following the mineralization process outlined by Sibal and Espino in 2018 [20].

2.6. Bacteriological analysis

Bacteriological analyses were conducted following the Most Probable Number (MPN) method. To ensure their reliability, prepared culture media underwent prior sterilization at 121°C for 20 minutes, followed by pH verification. Our study focused on evaluating fecal contamination, including enumeration of total coliforms, fecal coliforms, and streptococci. Samples were inoculated into a series of tubes containing broth lactose bromocresol purple (BCP) medium for total coliforms, then incubated at 37°C for 24 to 48 hours (presumptive test). Positive tubes were selected and transferred to a selective medium containing Brilliant Green Bile Broth (BLBVB) for fecal coliforms, then incubated at 44°C for 24 to 48 hours (confirmative test). As for streptococci, their enumeration was carried out by culturing samples in Roth broth, followed by incubation at 37°C for 24 to 48 hours (presumptive test). Positive tubes were then inoculated into a series of tubes containing Litsky culture medium, incubated at 37°C for 24 to 48 hours (confirmative test).

The results were expressed in terms of organism count per 100 milliliters, following statistical guidelines established by Mac Crady [21].

2.7. Statistical analysis

The results obtained were expressed as the mean of three experiments along with their standard deviation. The significance of the difference between the means was verified using t-tests and bidirectional analysis of variance (ANOVA). Tukey's multiple comparison tests, with a significance level of $p < 0.05$, were conducted using GraphPad Prism 9.

3. Results and Discussions

To assess the water quality of the Lower Sebou, we have proposed to measure certain physico-chemical parameters indicators such as turbidity, pH, dissolved oxygen, conductivity, temperature, nitrates, ammonium and nitrites, sulfates, chlorides, suspended matter, total phosphorus, NTK, biochemical oxygen demand, and trace elements.

3.1. Temperature

Water temperature influences many other parameters. This is primarily the case for dissolved oxygen (dioxygen), which is essential for aquatic life - fish respiration. Indeed, as the water temperature rises, the maximum amount of dissolved oxygen decreases. Therefore, excessively high-water temperatures in a river can lead to dramatic situations of dissolved oxygen deficiency, resulting in the disappearance of certain species, reduction in self-purification, accumulation of foul-smelling deposits (odors), and accelerated growth of vegetation (including algae). Fish cannot survive in temperatures that are too high. (Total mortality: River Trout at 27°C, Rainbow Trout at 29°C, Pike at 28°C, Perch and Tench at 30°C, Roach at 31°C, Carp at 38°C) [14,23]. In the study area, temperatures recorded during the dry season range from 26.76°C (P4) to 27.5°C (P1). These values are almost within the standard limit established by the Moroccan Standards for surface water, indicating average surface water quality in this study area (Figure 3) [22-23].

3.2. pH (Hydrogen Potential)

The average values observed at various sampling points indicate a slightly neutral to alkaline pH, with an average ranging between 7.81 to 7.95. These values are in accordance with Moroccan standards for the quality of surface waters (Figure 4) [22].

3.3. Electrical Conductivity

The measurement of conductivity is typically carried out at a temperature of 25°C or using a conductimeter equipped with automatic temperature compensation. In the absence of contaminants, very pure water acts as an insulator, exhibiting high resistance to electricity. However, the presence of natural mineral salts such as calcium, magnesium, sodium, and potassium, as well as pollutants, alters this conductivity. Consequently, conductivity provides a comprehensive assessment of all substances dissolved in water [18,24]. A significant increase in conductivity is observed in the presence of substantial organic pollution. Over the three study campaigns, conductivity shows an upward trend, with minimum values of 3.29µS/cm in campaign 1 and maximum values of 1455µS/cm in campaign 3 (Figure 5). Comparing our results to Moroccan standards governing surface water quality, we find that water quality is excellent for campaign 1, likely due to the sampling period (month 7) [23]. However, for campaigns 2 (month 8) and 3 (month 9), water quality is generally considered average. This decrease in quality is often associated with the arrival of the summer season, during which water flow decreases, leading to the drying up of riverbeds in most regions.

3.4. Dissolved oxygen

The dissolved oxygen content is a crucial indicator of the ecological balance of an aquatic environment, influencing the availability of numerous mineral salts, the decomposition of organic matter, and the survival of aquatic organisms, especially those contributing to the self-purification of watercourses [25-26]. Dissolved oxygen levels range between 4.9 mg/l (P1 - campaign 2) and 7.7 mg/l (P2 - campaign 1), generally indicating good quality surface waters of the Sebou River. However, this value significantly decreases at point P4 (campaign 2), highlighting a progressive deterioration in the quality of surface waters of the river in accordance with Moroccan standards [23,27]. This decrease can be attributed to increasing water temperature, scarce precipitation, and the presence of organic matter due to algae proliferation (Figure 6) [28].

3.5. Turbidity

It is a parameter that varies depending on colloidal compounds (clays, rock debris, microorganisms, etc.) or humic acids (plant degradation), as well as pollutants that cloud the water. Using a device (turbidimeter), we measure the resistance that the water offers to the passage of light to give it a value [14,29]. The recorded values show a considerable variation at each sampling campaign (Figure 7). This can be explained by the spatial and temporal variability of precipitation.

3.6. Suspended solids

Suspended solids refer to very fine particles in suspension (sand, clay, organic products, pollutant particles, microorganisms, etc.) that give a cloudy appearance to the water (turbidity) and hinder the penetration of light necessary for aquatic life. In excessive quantities, they thus constitute solid pollution of the water [14-29]. Overall, the concentrations of suspended solids show an increase at point P1 due to the significant load of organic and mineral matter from industrial activities (paper mill).

3.7. Chlorides

Waters containing significant amounts of chlorides are corrosive and have an impact on aquatic fauna, flora, and plant growth [27,30]. By comparing chloride levels in the four studied stations to Moroccan standards, it is evident that this water is of very poor quality, with a significant increase in chlorides (148.9 and 6027.01mg/l) during campaign 1 (Figure 8).

This increase can be attributed to the nature of the terrains traversed by these waters and the reduced water flow due to the drying up of the riverbed and evaporation phenomena, as this corresponds to the hottest period of the year and the proximity to the sampling points at the river mouth.

3.8. Sulfates

The high sulfate levels recorded in the Sebou River can be explained by the nature of the rocks traversed and bythe leaching of agricultural lands (Figure 9).

3.9. Ammonium

The presence of ammoniacal nitrogen reflects an incomplete degradation process of organic matter, but inputs from domestic, industrial, or agricultural sources should not be neglected [14-29]. The recorded values indicate a tendency towards qualitative deterioration of the surface waters of the river (Figure 10).

3.10. Nitrates

The nitrate analysis data reveal that the water is of excellent quality at the four stations studied, as they do not exceed 1.92 mg/l (Figure 11).

3.11. Nitrites

The nitrite averages show a decreasing gradient from upstream to downstream of the Sebou River, ranging from 0.42mg NO_2/l at P1 to 0.05mg NO_2/l at P4. The values obtained indicate excellent water quality according to Moroccan standards, as in all sampled sites, the concentration does not exceed 0.42 mg/l (Figure 12) [23].

3.12. Azote Kjeldhal (NTK)

The Kjeldhal nitrogen shows a steady increase throughout the three campaigns and across the four studied stations, reaching a maximum concentration of 12.65 mg N/l downstream during campaign 3, while being completely absent upstream during campaign 1. This rise in NTK concentration is associated with a deterioration in water quality, attributable to industrial and domestic discharges (Figure 13).

3.13. Biochemical Oxygen Demand for 5 days (BOD5)

The BOD5 of unpolluted surface water normally ranges from 2 to 20 mg/l. Beyond this range, harmful pollution to water quality and aquatic life can be suspected. The analysis of the spatial evolution of BOD5 values has shown relatively high BOD5 levels (Figure 14), mainly related to uncontrolled domestic liquid discharges [14-29].

3.14. Bacteriological Analysis

The bacteriological indicators of water quality most frequently used are total coliforms (TC), fecal coliforms(FC), and fecal streptococci (FS). They are considered as indicators of recent fecal contamination [14-29]. The results of the bacteriological analysis of the waters of the Sebou River indicate a high concentration of CF at point 1, due to the discharge from the paper industry, leading to a clear degradation of the water quality of the river (Table 4). As for the SF, the minimum value is recorded at point 4 (campaign 3), while the maximum value is observed at the same point 4 (campaigns 1 and 2), highlighting an alteration of the bacteriological quality due to industrial activity (factory). These results are in line with Moroccan water quality standards. Comparing our results with these standards shows that the waters of the Sebou River do not exhibit significant biological contamination (Figures 15 & 16), and according to the Moroccan surface water quality assessment, these waters generally have an average quality in terms of fecal coliforms (CF) and fecal streptococci (SF) levels [15,22]. Overall, the analysis of this study has led to the following conclusions:

- Bacteriological quality exhibits spatiotemporal variability.
- Bacteriological contamination is associated with runoff during floods, as well as industrial effluents.
- The quality of surface waters in the study area is considered average.

In recent years, rapid economic development has caused heavy metal pollution to emerge as a significant global environmental concern [31-32].

Table 1: Methods and standards used for water sample analysis [19].

Analyzed parameters	Unit	Norme	Methods
Nitrates	mg/l	NF T 90-012	Method with Sodium Salicylate
Nitrites	mg/l NO_2	NF T 90-01	Method with N-1-Naphthyl Ethylenediamine
Ammonium	mg/l NH4+	NF T 90-015	Method Indophenol Blue
NTK	mg/l TN	NF T 90-016	Oxydation thermique à 1200°C
Total Phosphorus	mg/l	NF T 90-012	Method Assay after Oxidation with Persulfate
Orthophosphates	mg/l	NF T 90-023	Ammonium Molybdate Method
Sulfates	mg/l	NF T 90-040	Nephelometry Method
Chlorides	mg/l	NF T 90-014	Mohr Volumetric Method
Chemical Oxygen demand ‘COD”	mg d’O_2/l	NF T 90-101-2001	Oxidation by Potassium Dichromate
Biochemical Oxygen Demand BOD"	mg d’O_2/l	NF in 1899 -1998	OxiTop Method

Table 2: Average values of the physico-chemical parameters of the studied waters.

Parameters	P1	P2	P3	P4
NH4+ mg/l	0,58	0,34	0,31	0,28
$NO2^-$ mg/l	0,42	0,06	0,05	0,05
$NO3^-$ mg/l	0,72	1,67	1,25	1,55
NTK (mg N /l)	5,31	6,46	6,21	6,22
DBO 5 mg/l	11	3,66	3,6	2,66
SM mg/l	154,33	80	61,33	62
P total mg/l	0,14	0,07	0,063	0,1165
Sulfate (mg/l)	85,8	139,26	241,93	287,8
Cl g/l	491,61	1708,83	2294,99	2294,99
T °c	27,5	27,3	26,93	26,76
pH	7,87	7,81	7,95	7,87
Turbidity (NTU)	303,98	202,12	152,87	152,54
Conductivity µs/l	751,76	739,5	762,74	790,84
Dissolved O2	5,23	6,63	6,45	6,34
Iron (ppm)	90,88	46,19	18,19	22,58

Table 3: Surface water quality grid according to Moroccan standards [22].

Parameters		Units	***Class 1***	***Class 2***	***Class 3***	***Class 4***	***Class 5***
			Excellent	Good	Moderate polluted	Polluted	Very polluted
Organoleptic							
1	Color (Pt scale)		<20	20-50	50-100	100-200	>200
2	Odor (diluted at 25°C)		<3	3-10	10-20	>20	
Physicochemical							
3	Temperature	°C	<20	20-25	25-30	30-35	>35
4	pH		6.5-8,5	6,5-8,5	6,5-9,2	<6,5 or >9,2	<6,5 or >9;2
5	Conductivity	µs/cm	<750	750-1300	1300-2700	2700-3000	>3000
6	Sulfates	mg/l	<200	200-300	200-250	750-1000	>1000
7	Chlorides	mg/l	<100	100-200	200-1000	250-400	>400
8	Suspended Matter (SM)	mg/l	<50	50-200	50-200	1000-2000	>2000
9	Dissolves O2	mg/l	>7	7-5	5-3	3-1	<1
10	DBO5	mg/l	<3	3-5	5-10	10-25	>25

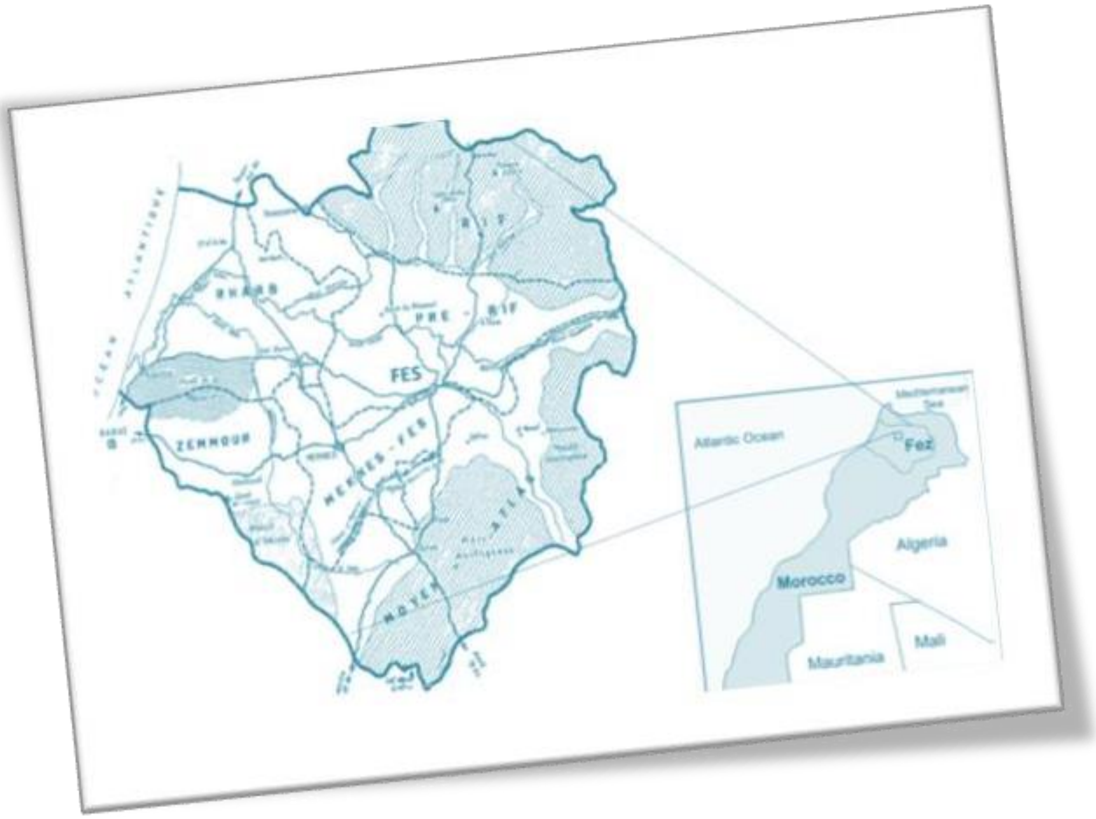

Figure 1: Geographical Location of the Sebou Basin.

Figure 2: Geographic Location of Sampling Sites along the Oued Sebou.

Table 4: Average values of bacteriological parameters of the studied waters.

	P1	P2	P3	P4
CT UFC/100ml	291,33	259	171,5	400,33
SF UFC/100ml	76,33	65,83	26	89,66

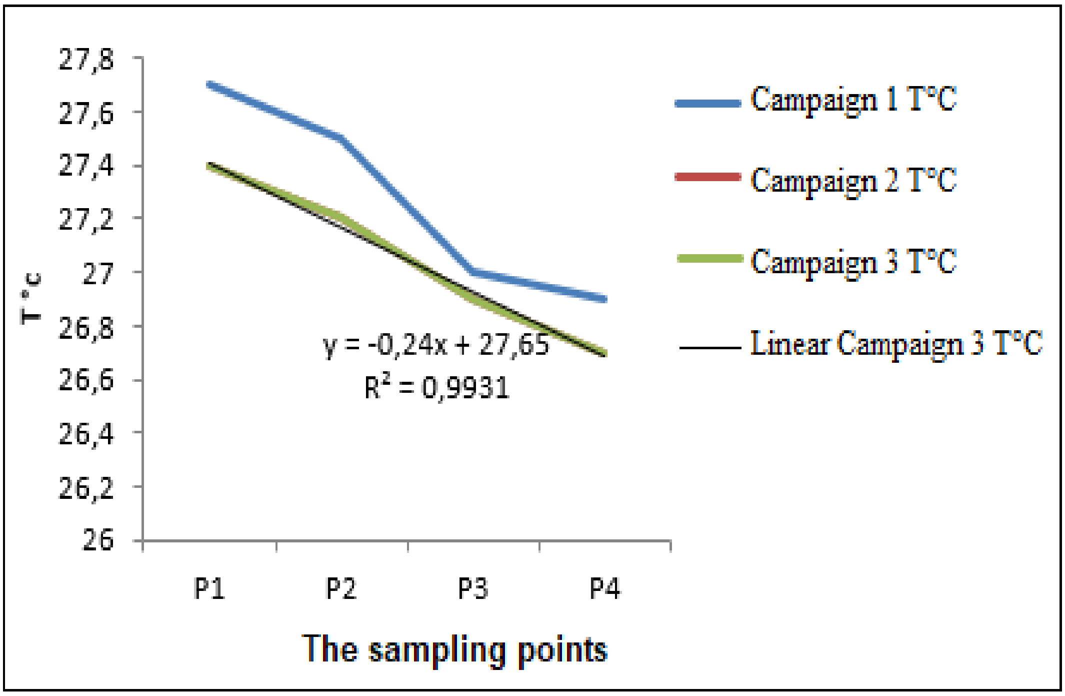

Figure 3: Spatial evolution of the temperature of the surface waters of the Sebou River.

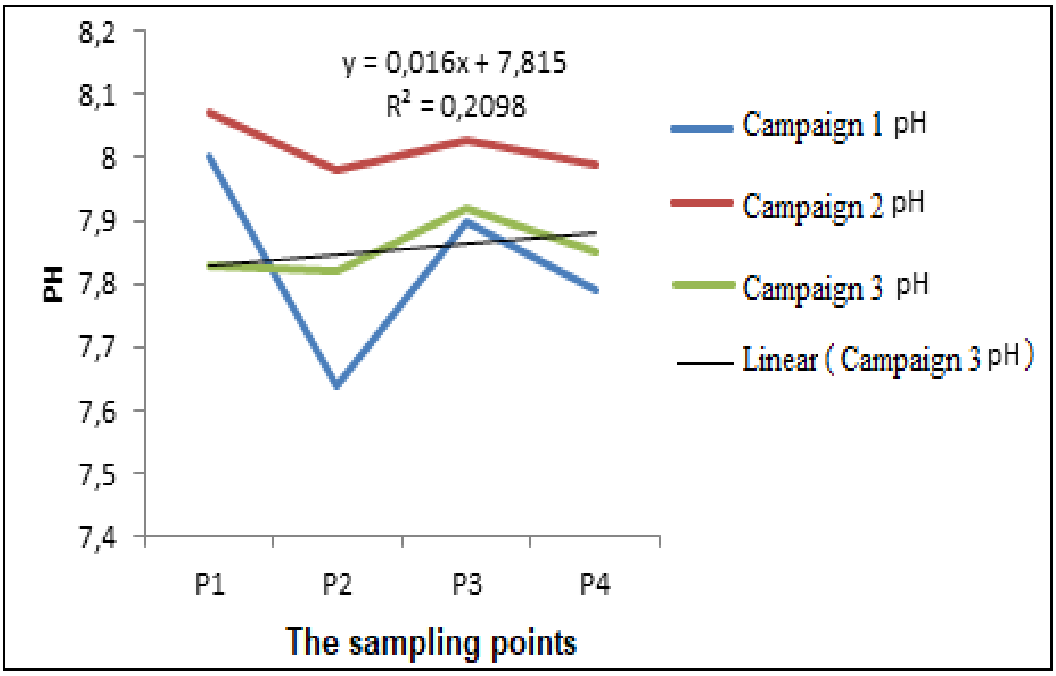

Figure 4: Spatial Evolution of the Hydrogen Potential of the Surface Waters of the Sebou River.

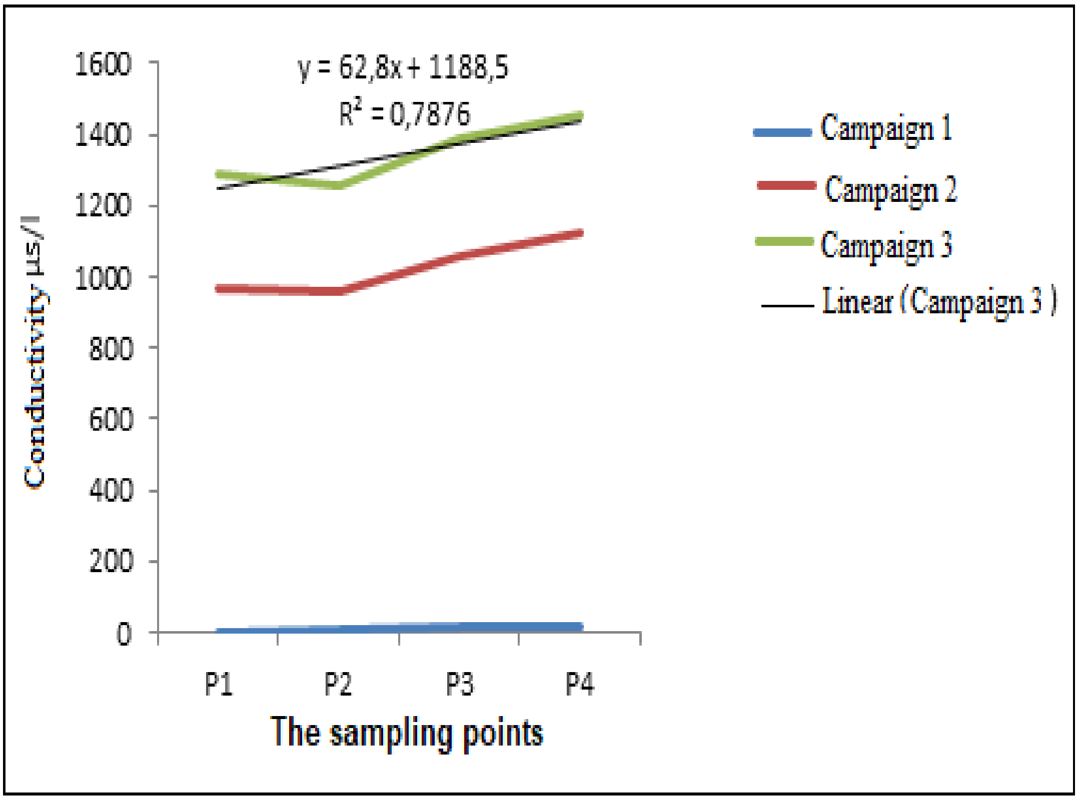

Figure 5: Spatial Evolution of the Electrical Conductivity of the Surface Waters of the Sebou.

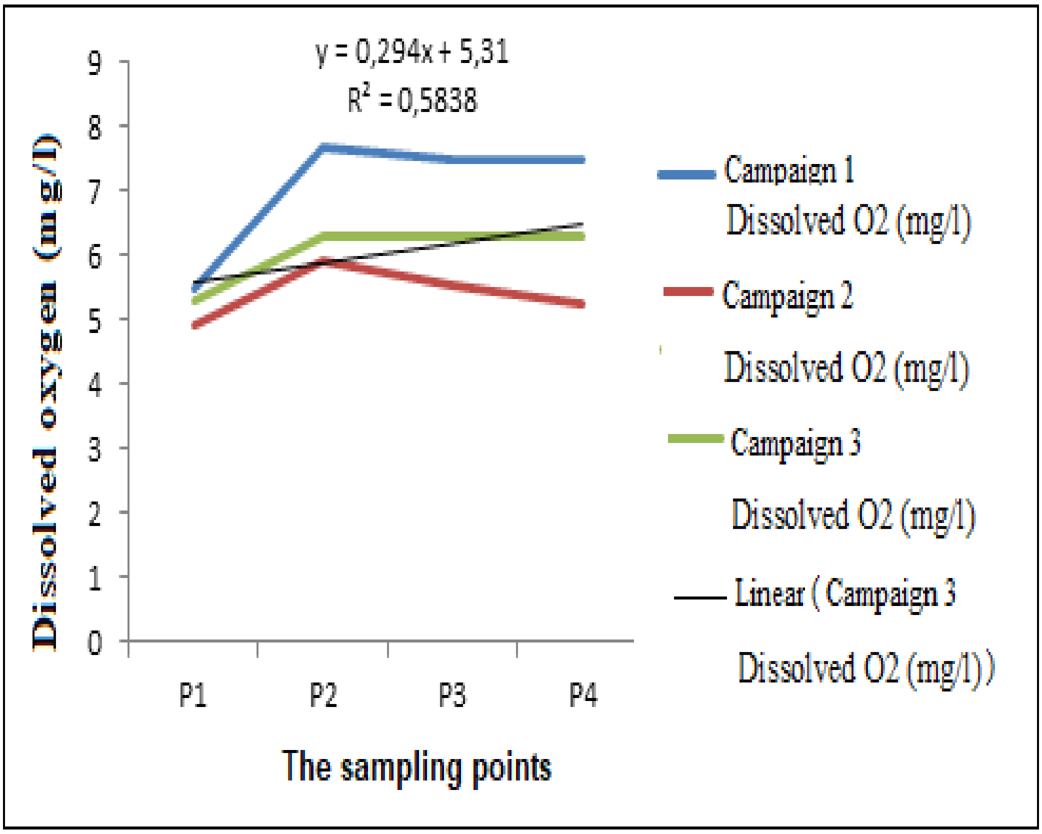

Figure 6: Spatial Evolution of Dissolved Oxygen in the Surface Waters of the Sebou River.

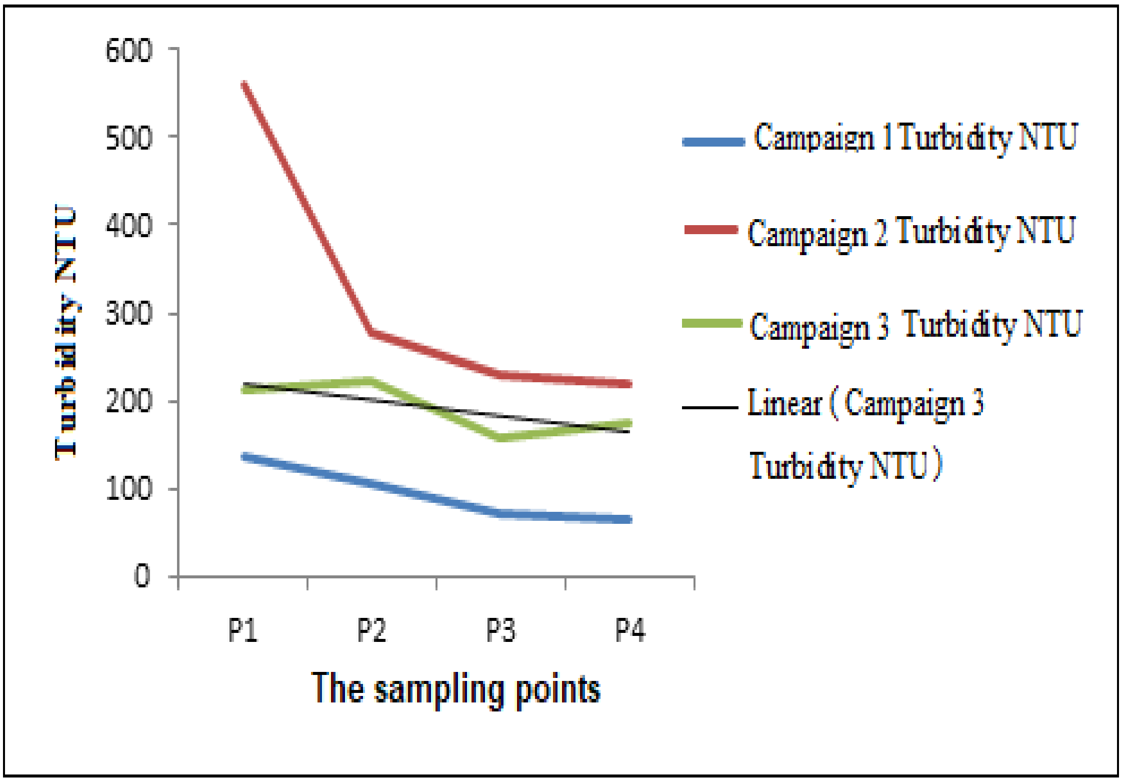

Figure 7: Spatial Evolution of Turbidity in the Surface Waters of the Sebou River.

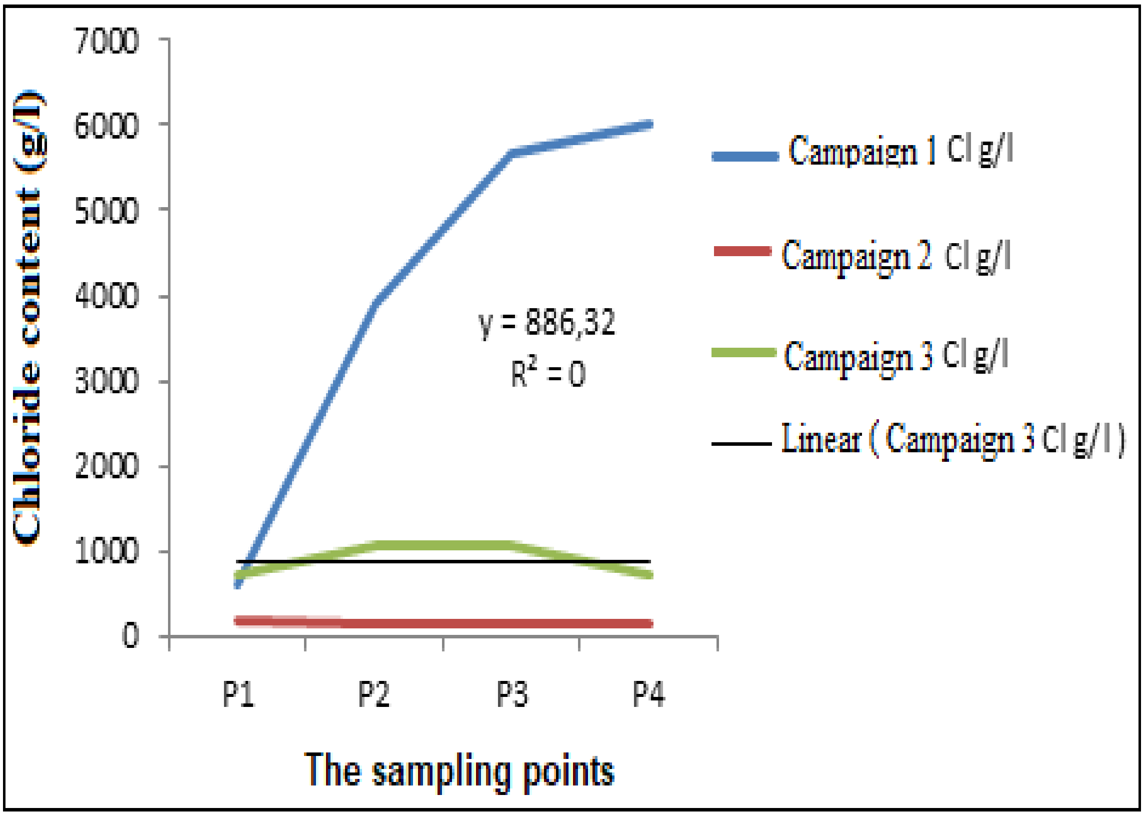

Figure 8: Spatial Evolution of Chloride Content in the Surface Waters of the Sebou River.

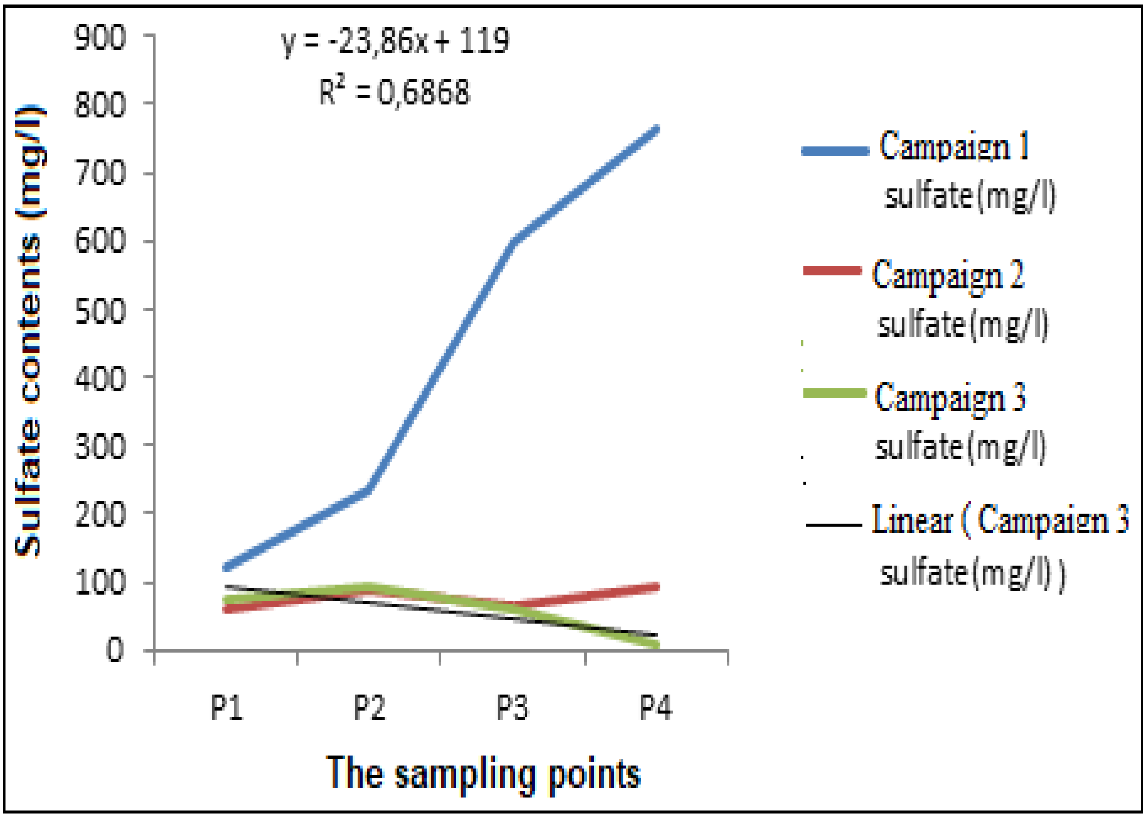

Figure 9: Spatial Evolution of Sulfate Content in the Surface Waters of the Sebou River.

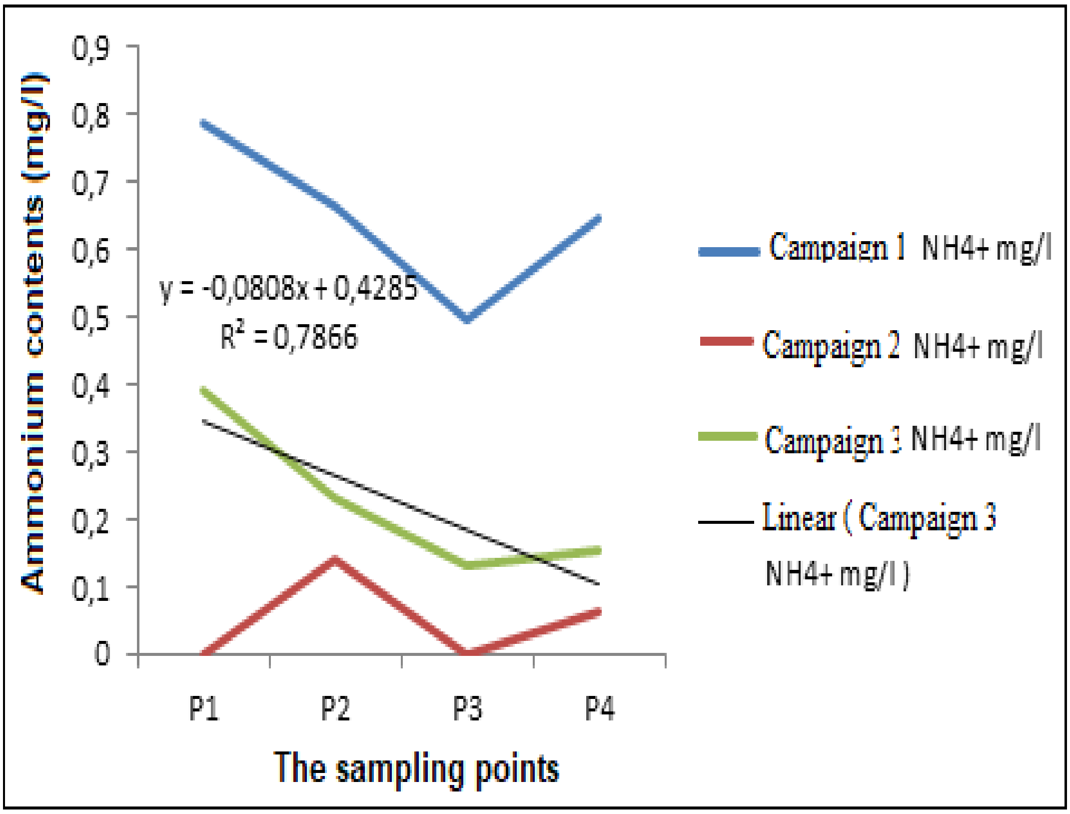

Figure 10: Spatial Evolution of Ammonium Content in the Surface Waters of the Sebou River.

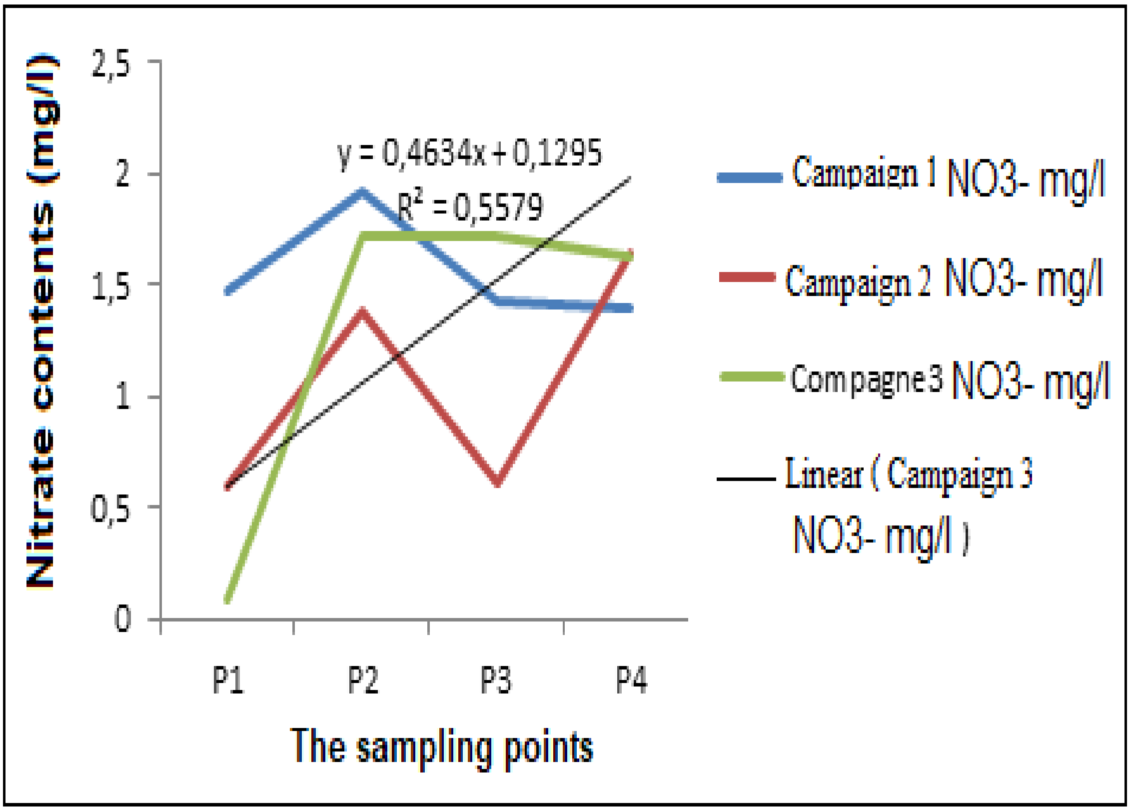

Figure 11: Spatial Evolution of Nitrate Content in the Surface Waters of the Sebou River.

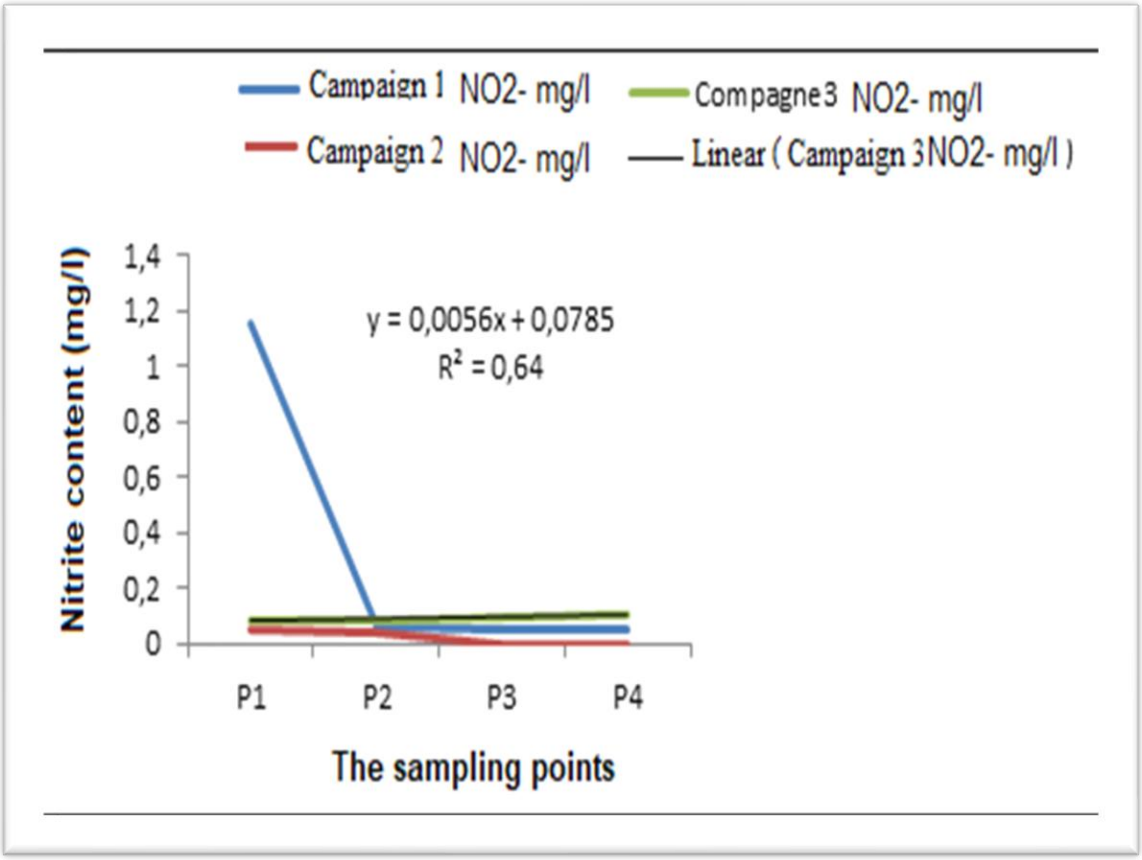

Figure 12: Spatial Evolution of Nitrite Content in the Surface Waters of the Sebou River.

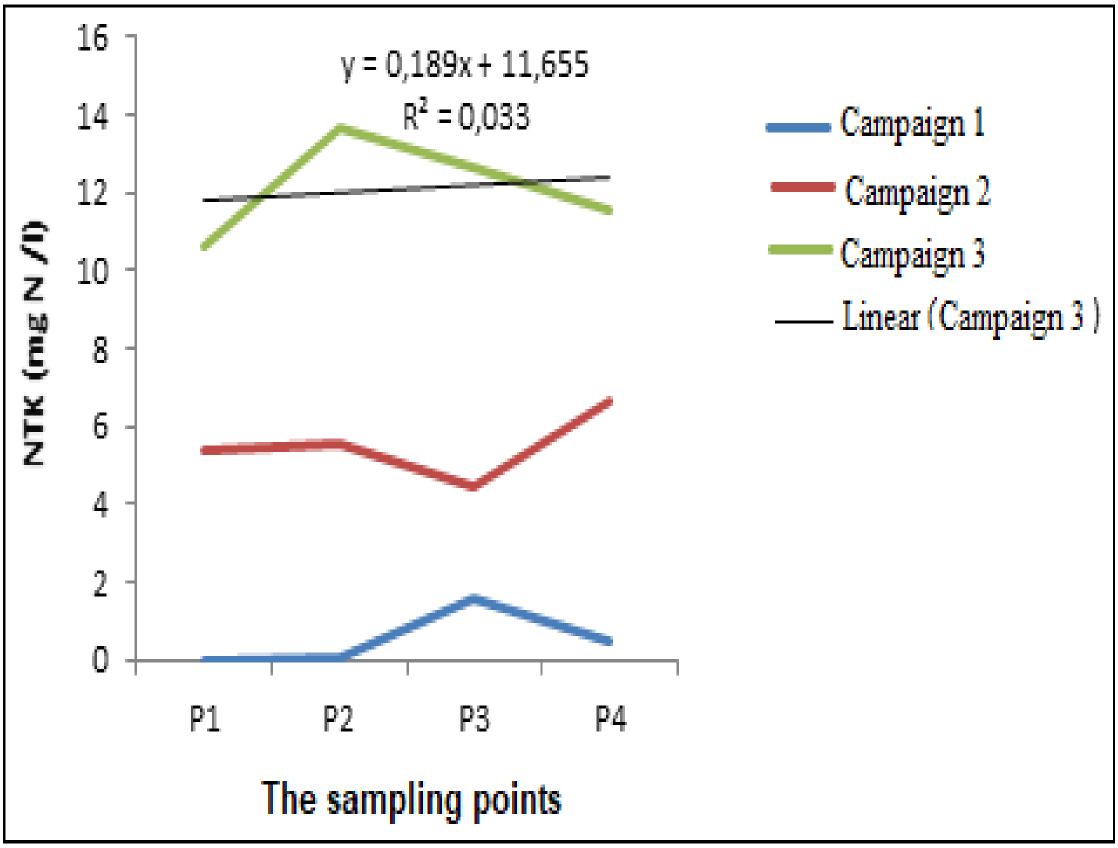

Figure 13: Spatial Evolution of NTK Content in the Surface Waters of the Sebou River.

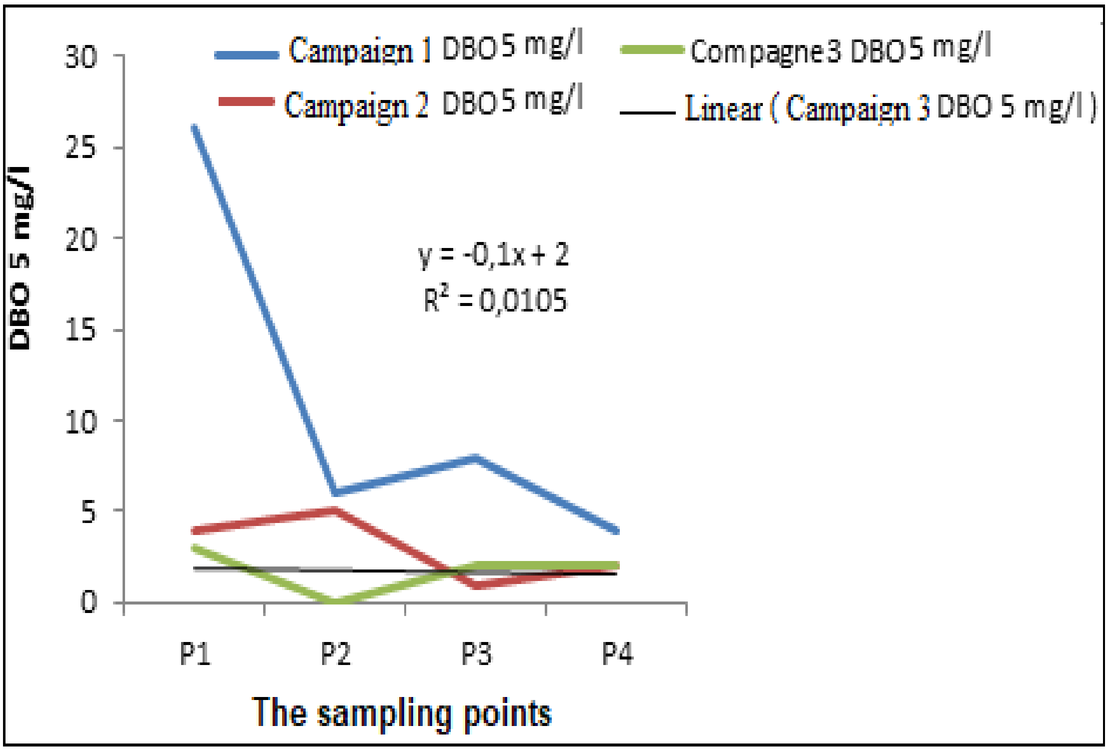

Figure 14: Spatial Evolution of BOD5 Values of the Surface Waters of the Sebou River.

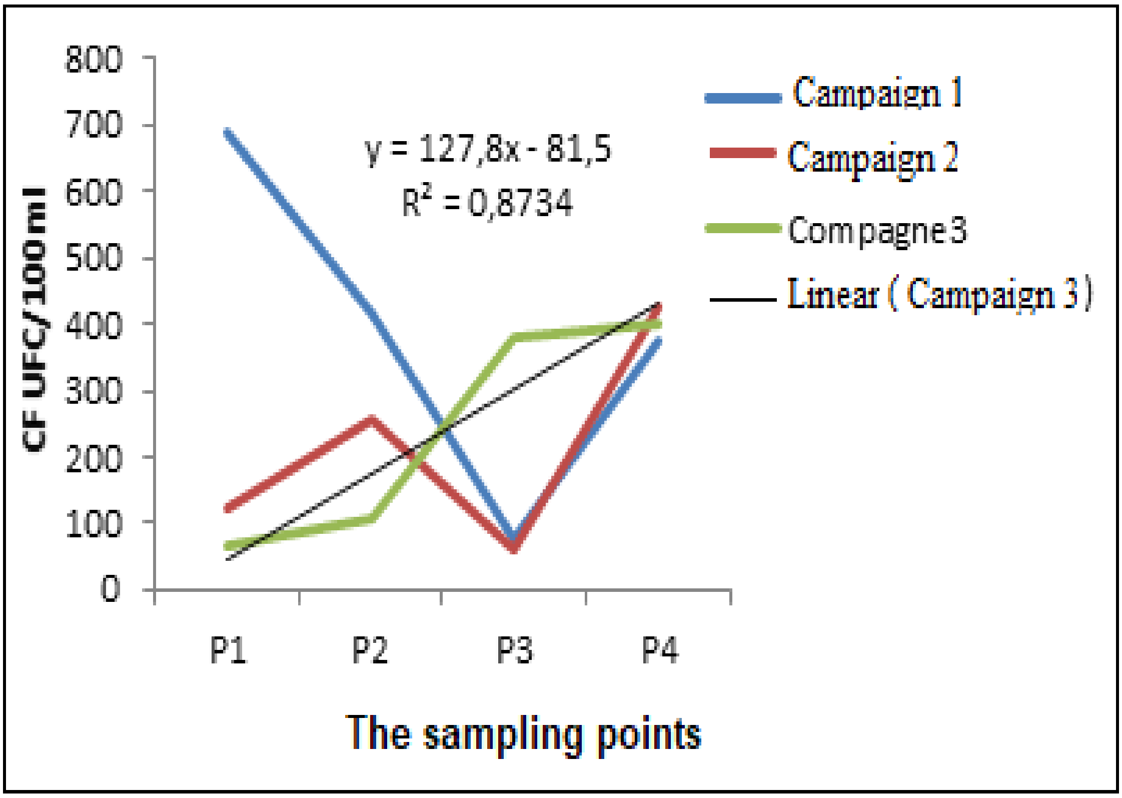

Figure 15: Spatial Evolution of Fecal coliforms (CF) in the Surface Waters of the Sebou River.

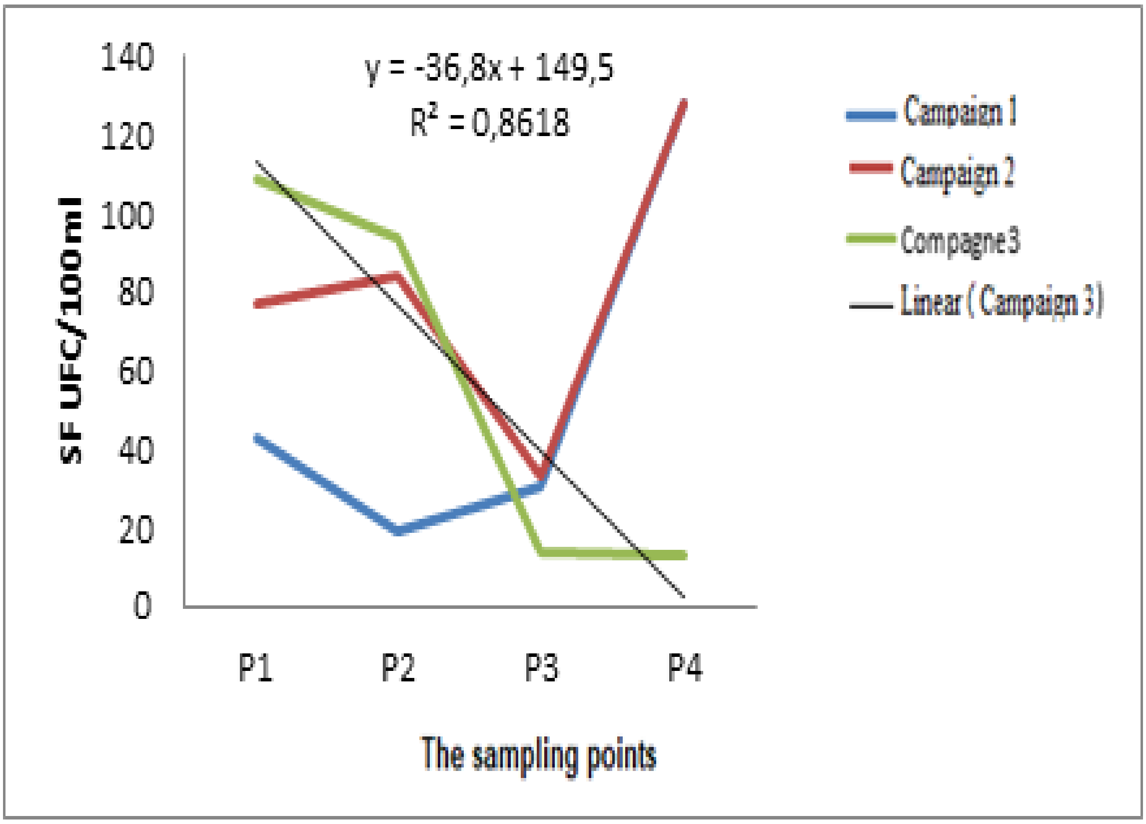

Figure 16: Spatial Evolution of Fecal Streptococci (FS) in the Surface Waters of the Sebou River.

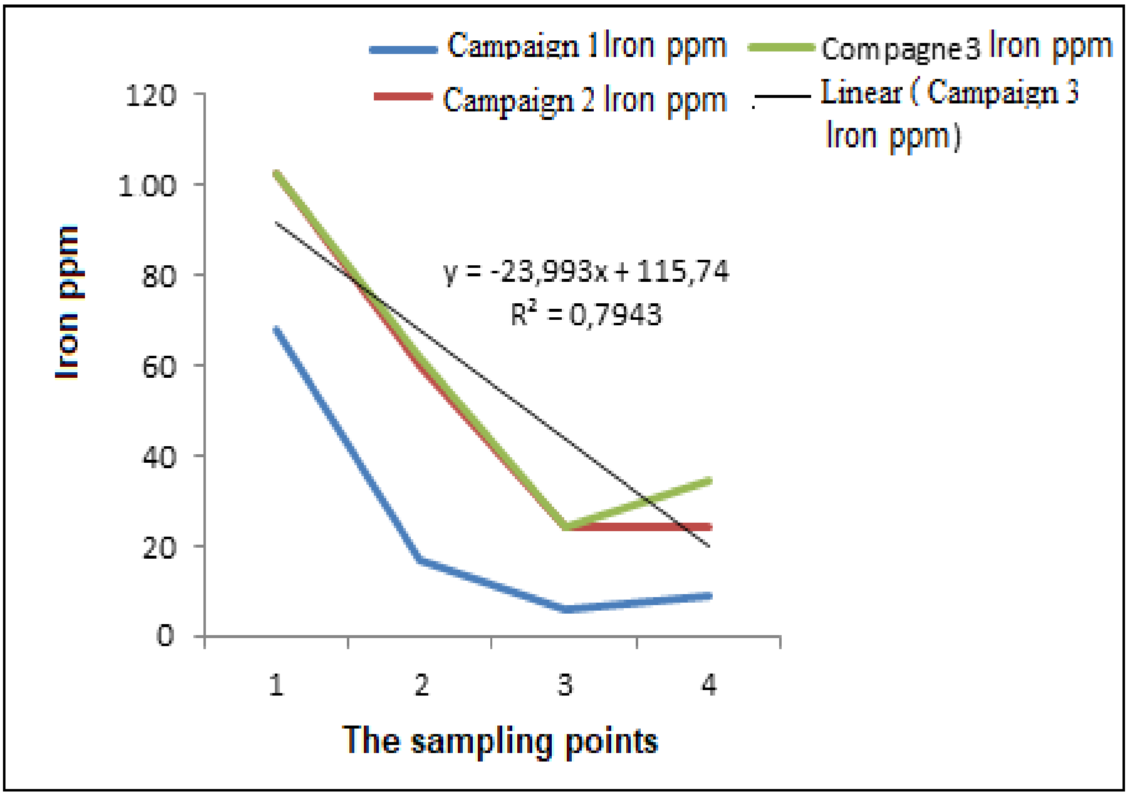

Figure 17: Spatial Evolution of Iron in the Surface Waters of the Sebou River.

3.15. Trace elements

The analysis of metals in the waters of the Sebou River reveals their presence at minimal levels, with concentrations not exceeding 0.06 ppm. These levels, well below the limits recommended by Moroccan standards, pose no risk to the quality of this water (Figure 17). However, higher concentrations of iron have been detected, suggesting pollution of surface waters by heavy metals, attributable to industrial activity in the studied region. This correlation explains the decreasing trend observed in the curve : as one moves away from industrial zones, the iron concentration decrease.

4. Conclusions

The findings from both physicochemical and bacteriological analyses highlight a degradation in water quality, particularly downstream of sampling sites affected by industrial wastewater discharge from the city of Kenitra - specifically from the paper mill. The overall assessment of water resource quality indicates that the rivers generally exhibit moderate quality. However, degradation in water quality is primarily attributed to natural factors, with deterioration typically occurring during the summer months due to decreased water flow. It's important to emphasize that this summary offers a concise overview of the physicochemical and bacteriological analyses conducted on the waters of the Sebou River. This study aims to contribute theoretically and practically to a better understanding of the correlation between wastewater discharge, water quality, environmental health, and human health. Ultimately, this contributes to the preservation of water resources and the broader goals of environmental protection and management. The areas where recorded values do not meet Moroccan standards are predominantly located at P1 and P2, upstream and downstream of the paper mill, which serves as the primary source of pollution for the surface waters of the Sebou River. However, the imperative for preserving water resources is clear. To mitigate the impact of polluted discharges on the quality of the Sebou waters, pretreatment of domestic, agricultural, and industrial wastewater before discharge into the natural environment is highly recommended. Furthermore, conducting more comprehensive studies on the origins of this pollution is also advisable.

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Conflict of Interest

The authors declare that there is not any conflict of interests regarding the publication of this manuscript.

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