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Physico-chemical characterization of the quality of irrigation water used in urban agriculture next to a textile factory in Bouake, Côte d'Ivoire

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Abstract

In order to assess the physico-chemical characteristics of waters used for watering vegetable crops around a textile factory in Bouaké, a study was carried out on 68 water samples from four sites (site B, site Mp, site P and site Me). These samples were collected over two campaigns, in February and July 2018 corresponding respectively to the dry and rainy season. The analysis revealed high values of temperature (32.13 ± 0.94°C), pH (12.09 ± 0.05), conductivity (8594.2 ± 391.32 µS/cm), TDS (4347.3 ± 37.91mg/L), COD (523.42 ± 66.21 mgO_2/L), orthophosphates (0.6 ± 0.05 mg/L), ammonium (3.53 ± 0.33mg/L) and negative values of the redox potential (-270.77 ± 9.02 mV) at the nearest site and downstream of the textile effluent during the dry season. Most of the parameter values analyzed on this site (site Mp) do not comply with the quality criteria for irrigation water, especially during the dry season. Due to their high salinity, these waters are not recommended for irrigation. These results show the degradation of water quality by the textile effluent, marked by significant spatio-temporal variations. The principal component analysis (PCA) corroborated the results obtained by the physico-chemical analysis.

1. Introduction

Water is an important resource for human survival [1, 2]. It is essential for industrial, commercial and agricultural activities. However, through his activities human being participates in water degradation, endangers its availability and thus limits its use for future generations [3]. Agriculture, in general uses much water [4]. Over the world, 324 million hectares are irrigated [5]. Due to the increasing scarcity, availability of water resources and population growth, farmers have to resort to different water sources for watering their crops [6]. At some sites, they often use surface water, well water and even untreated wastewater from households and industries as well [7]. Thus, in urban areas of many developing countries, urban or peri-urban agriculture depends, to some extent at least, on wastewater as a source of irrigation water [8]. They constitute an interesting alternative thanks to their availability and their agronomic value [9, 10]. It is considered by farmers as a regular water resource, abundant, rich in nutrients and for free [11]. However, the use of untreated wastewater is the cause of negative impacts on both the environment and the health of the populations [9, 11, 12, 13]. Likewise, the scarcity of water allocated to agriculture compels farmers to favor the use of poor quality groundwater (wells) and its use brings about consequences on soil quality [1, 14]. According to the precautionary principle, some organizations such as the FAO have issued quality standards for water aiming at irrigating. Côte d'Ivoire, like many countries in the world, adopted laws regulating discharges and emissions from installations classified for the protection of the environment [15], in order to prevent risks. Côte d'Ivoire after the success of its agriculture, just after its independence, motivated and founded its industrial policy on valuating raw materials. This is how the Ivorian industrial sector is full of a panoply of companies grouped together in various sectors of activity which are: agro-industry, textiles, chemical and derivative sector, wood processing, mining and energy sector [16]. The Gbêkê region, with its capital Bouaké, is the most industrialized area in the inner country. Before the socio-political and military crisis of 2002, it was second at the national level thanks to several existing industrial units shared between the textile, agrifood and chemical branches [17]. These industries, mainly the one of textiles produces effluents that are often a little bit or not biodegradable [18], which are very often highly charged with organic and chemical materials and which sometimes have a large spectrum of solid or dissolved pollutants, at various levels of toxicity [13, 19]. These industrial discharges are essentially thrown into the natural environment (rivers, seas, lakes and soils) [20] without prior treatment or with an insufficient treatment [21], mainly in a network of gutters (sewage systems). The textile waste is then diluted by the overflow of water from the Gonfreville dam located upstream of the textile factory. In search of water or in order to improve yields, farmers use either water from the dam, diluted effluent, or water from the well to irrigate their vegetable crops. These are located near water from the dam and around the factory. Thus, the main objective of this study is to assess the physicochemical characteristics of the water used for watering vegetable crops around the textile factory in Bouaké.

2. Material and Methods

2.1. Presentation of the study area

The city of Bouaké is part of the Gbêkê region located in the Center-North of Côte d'Ivoire, 370 km from the economic capital Abidjan (Figure 1). It is located between latitudes 7°45'N and 7°38'N and longitudes 5°7'W and 4°58'W with an area of 71 km^2. It is characterized by a humid tropical climate marked by four seasons: a long dry season (from November to February), a small dry season (from July to August), a long rainy season (from March to July) and a small rainy season (from September to October). The temperature varies between 25 and 38°C, with a rainfall varying from 1000 mm to 1700 mm. The Bouaké textile factory is located in the northwest of the city, in the Gonfreville district (Figure 1). Around that factory, many crops and vegetables are cultivated by farmers. They cultivate okra, eggplant, pepper, onion, lettuce, tomato, cabbage, carrot, etc. Upstream, a dam was built up on the Loka stream and its water is used both in the various transformation processes in factory and by farmers for watering their crops. Downstream, we can find the wells and the effluent diluted by the dam water which irrigates some farms.

2.2. Description of sampling sites

Four sampling sites were chosen near the textile factory, taking into account the nature of the water (surface water, industrial effluents and well water) and the activities that took place (domestic, industrial and agricultural activities). They are denoted B, Mp, P and Me (Figure 2). The sampling points are between latitudes 7°43'13.15"N and 7°43'16.03"N and longitudes 5°3'13.04"W and 5°2'41. 28"W. On the various sites, 34 sampling points were selected and distributed as follow:

- site B (water from the dam upstream of the textile factory) comprising 10 points named A1 to A10)
- site Mp (mixture of water from the dam and raw effluent near the plant) includes 10 points named

A11 to A20;

- site P containing 4 traditional wells located between the sites Mp and Me noted A21 to A24;

- site Me (mixture of water from the dam and the raw effluent downstream) also includes 10 points named A25 to A34 (figure 2).

Figure 1: Location of the study area

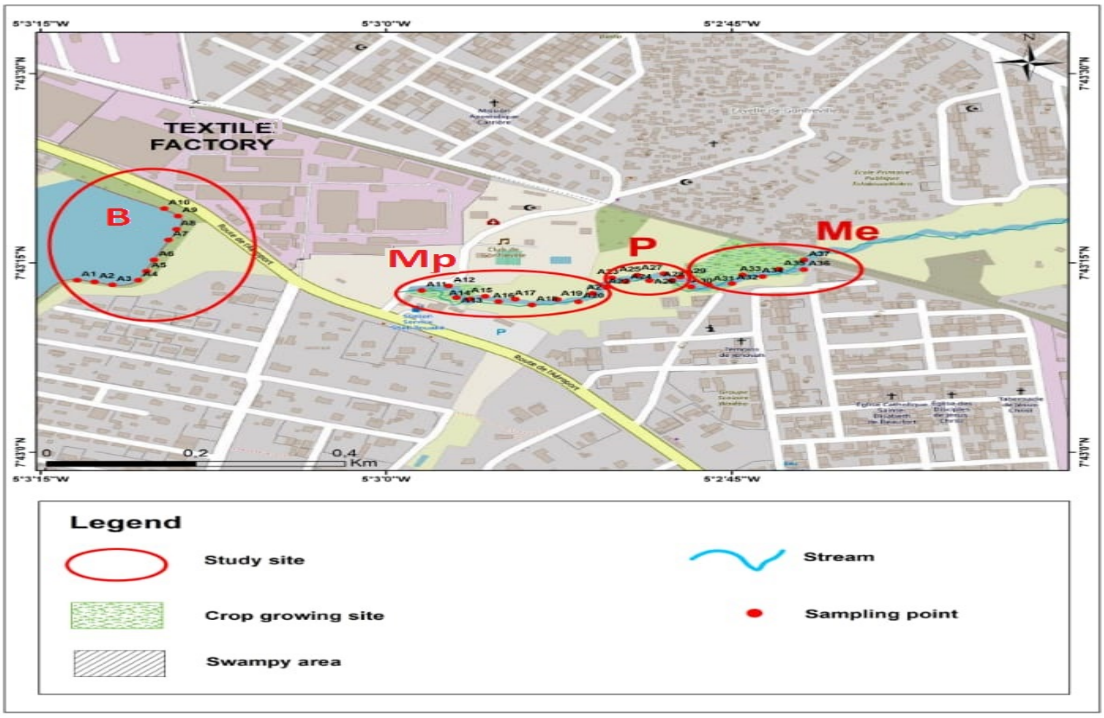

Figure 2: Presentation of sampling points

2.3. Sampling methods

The study was carried out over two campaigns. The first sampling campaign was carried out in February 2018, during the dry season and the second in July 2018, in the rainy season. During these campaigns, water samples were taken in 300mL polyethylene bottles. These bottles were pre-washed in detergent and rinsed with tap water and then with distilled water. Before sampling, each bottle is rinsed with the water to be analyzed. The water sample was taken from a depth of 15 to 30 cm from the water surface, avoiding the penetration of air and any kind of contamination of the sample. During the two campaigns, a total of 68 water samples were taken. To ensure a good state of preservation, the samples were protected from light and refrigerated at a temperature of 4°C in a cooler. They were then transported to the laboratory for analysis.

2.4. Measurement of physico-chemical parameters

Temperature, pH and redox potential were measured by using the previously calibrated HANNA HI 8424 hand-held multiparameter. The electrical conductivity and the total dissolved solids were measured by means of the HANNA HI 9835 conductivity meter. As for the turbidity, it was measured by the HANNA HI 93703 turbidimeter. All these measurements except for the turbidity were carried out in situ. The orthophosphate, ammonium and nitrate ions were determined by methods approved by the French Association for Standardization (AFNOR). These parameters were determined in a colorimetric way by using a UV/VIS-JASCO V-530 molecular absorption spectrophotometer at wavelengths of 880nm, 420nm and 415nm respectively. Chemical oxygen demand (COD) was carried out by the method described by [22] using a Milton spectrophotometer at the wavelength of 600 nm. The principle of that method is to oxidize in an acidic medium by excess of potassium dichromate at a temperature of 150°C of oxidizable materials in the presence of silver sulfate as a catalyst, and mercury sulfate which reduces the interference caused by the presence of chloride ions.

2.5. Statistical analysis

The data collected was processed by using Statistica 7.1 software. That software was used to compare the averages of the different physicochemical parameters between sites and between seasons by performing Duncan's ANOVA variance tests at a risk significance level $\alpha = 5\%$ ($p < 0{,}05$). It was also used to perform a principal component analysis (PCA) which made it possible to determine the link between the variables among themselves and between the variables and the individuals acting in the irrigation water.

3. Results and discussion

3.1. Results

3.1.1. Variation of physical parameters

The average values of the physical parameters of the irrigation water taken in the dry season (DS) and in the rainy season (RS) are shown in Table 1.

Temperature

The lowest irrigation water temperature values are noticed in the dam water (site B) with averages of around 29.1 ± 0.39°C during the dry season and 27.93 ± 0.61°C during the rainy season. The highest average value (32.13 ± 0.94°C) was found at the level of the raw effluent-water mixture of the dam (site Mp) upstream during the dry season. In addition, in the rainy season, a slight decrease happens (29.46 ± 0.86°C) on that site. As for well water (site P), the average temperature values noticed are substantially identical over the two seasons with values of the order of 30.3 ± 2.38°C during the dry season and 29.07 ± 1.59°C during the rainy season.

Table 1: Average values of the physical parameters of irrigation water

T: temperature; pH: Hydrogen potential, Eth: Redox potential; EC: Electrical conductivity; TDS: Total dissolved solids;

		Sites				
Parameters	**Seasons**	**B**	**Mp**	**P**	**Me**	**Irrigation standards**
T(°C)	DS	29.1±0.39^{2b}	32.13±0.94^{1b}	30.3±2.38^{3a}	31.42±0.72^{1b}	35
	RS	27.93±0.61^{3a}	29.46±0.86^{1,2a}	29.07±1.59^{1a}	30.26±0.42^{2a}	
pH	DS	7.00±0,13^{1b}	12.09±0.05^{4b}	8.12±0.39^{2a}	10.68±0.57^{3b}	6.5 – 8.4
	RS	8.41±0.1^{1,2a}	9.64±0.44^{3a}	8.00±0.36^{1a}	8.79±0.49^{2a}	
Eth(mV)	DS	8.61±5.4^{4b}	-270.77±9.02^{1a}	-48.07±28.82^{3a}	-187.64±25.98^{2a}	-
	RS	-73.94±11.09^{1a}	-59.54±2.47^{2b}	-36.9±15.14^{3a}	-68.36±5.04^{1,2b}	
EC(µS/cm)	DS	232.34±8.93^{1b}	8594.2±391.32^{4b}	1366±756.84^{3a}	903.4±37.05^{2b}	3000
	RS	203±7.25^{1a}	274.67±37.91^{1,2a}	670±176.45^{3a}	338.37±76.38^{2a}	
TDS(mg/L)	DS	116.03±4.39^{1b}	4347.3±37.91^{4b}	687.25±382.68^{3a}	463.1±40.15^{2b}	2000
	RS	100.82±4.13^{2a}	134.11±19.19^{1a}	338.75±88.55^{3a}	164.79±11.78^{2a}	
Turb(NTU)	DS	1.562±0.6^{1a}	4.04±0.75^{1a}	13.015±9.25^{3a}	8.063±3.13^{2a}	-
	RS	6.538±1.38^{1b}	7.67±1.79^{1b}	32.95±24.91^{2a}	15.76±3.23^{1b}	

Turb: Turbidity. DS: Dry season; RS: Rainy season. For each physical parameter, the values with letters a and b in exponent present a significant difference ($p < 0.05$) between the seasons for the same site and those affected by the numbers 1, 2, 3 and 4 by exponent present a significant difference ($p < 0.05$) between the sites for the same season.

More downstream from the plant, the raw effluent-water mixture from the dam (site Me) records average temperatures of around 31.42 ± 0.72°C in the dry season and 30.26 ± 0.42°C in the rainy season. There are significant differences at the 5% threshold ($p < 0.05$) between average temperature values at the different sites from one season to another, with the exception of site P where the variation in parameters is statistically low ($p > 0.05$).

pH

All the water for irrigating the vegetable crops studied has an alkaline character (pH ranging from 8.00 ± 0.36 to 12.09 ± 0.05) except for water from the dam which has a neutral tendency during the dry season (Table 1). The average pH values of dam water are around 7.00 ± 0.13 during the dry season and 8.41 ± 0.1 during the rainy season. For the site Mp, the raw effluent-dam water mixture is very alkaline with pH values of around 12.09 ± 0.05 in the dry season. During the rainy season, the pH drops to 9.64 ± 0.44 at this site. In the domain of well water, the pH undergoes a slight variation between the two seasons with average values of 8.00 ± 0.36. Downstream, the raw effluent-dam water mixture undergoes a significant drop in pH. The average values are 10.69 ± 0.57 in the dry season and 8.79 ± 0.49 in the rainy season. The pH values of irrigation water are significantly different ($p < 0.05$) between the two seasons with the exception of site P and also between the different sites.

Conductivity

The analysis of the average values of the conductivity of the water at the level of the dam shows an average mineralization with values of 232.34 ± 8.93µS/cm and 203 ± 7.25µS/cm recorded respectively during the dry season and the rainy season (Table 1). Unlike dam water, the raw effluent-dam water mixture (site Mp) shows very high mineralization during the dry season with a conductivity of 8594.2 ± 391.32µS/cm. However, this value undergoes a significant drop in the rainy season, of about 274.67 ± 37.91µS/cm. In addition, the conductivity values of the well water and the effluent-water mixture of the dam show an accentuated mineralization with higher averages in the dry season (1366 ± 756.84µS/cm (site P) and 903.4 ± 37.05µS/cm (site Me)) than in the rainy season (670 ± 176.45µS/cm (site P) and 338.37 ± 76.38µS/cm (site Me). Except for the site P, all average conductivity values are significantly higher during the dry season ($p < 0.05$) and the conductivity value of dam water differs significantly from the values of those of the near-plant mixture, well water and the distant mixture ($p < 0.05$) in the dry season During the rainy season, the conductivity value of the mixture close to the factory is significantly equal ($p > 0.05$) to that of the water from the dam and the distant mixture.

Total dissolved solids (TDS)

The evolution of TDS is parallel with the one of conductivity. The average TDS values fluctuate between 100.82 ± 4.13 mg/L (site B) in the rainy season and 4347.3 ± 37.91 mg/L(site Mp) in the dry season (Table 1). Significantly higher ($p < 0.05$) in the dry season than in the rainy season. The TDS values downstream of the textile plant are higher than those upstream.

Turbidity

The lowest and highest turbidity values are obtained in the dry season with respectively 1.56 ± 0.60 NTU (site B) and 32.95 ± 24.91NTU (site P) (Table 1). Irrigation water has a higher turbidity in the rainy season than in the dry season. These values show that water of the dam is clear (NTU <5) in dry season compared to other sites where water is generally cloudy (NTU> 5). They also show that the turbidity at all sites downstream of the textile factory is greater than the one of site B located upstream. All the turbidity values in the rainy season are significantly higher than those of the dry season.

Redox potential

The spatio-temporal variations in the redox potential of the irrigation water studied indicate negative average values at all sampling sites except site B, which has a positive value during the dry season (Table 1). The average values recorded vary between -270.77 ± 9.02 mV (site Mp) and 8.61 ± 5.40 mV (site B). On all sites, the values obtained in the rainy season are higher than those in the dry season except for those at site B. In the dry season, the values of the redox potential are very low on the sites downstream of the factory.

3.1.2. Variation of chemical parameters of irrigation water

Table 2 shows the average values of the chemical parameters of the sprinkling water.

Ammonium

The average ammonium levels recorded in the irrigation water samples are between 0.06 ± 0.05 mg/L (site B) and 3.53 ± 0.33 mg/L (site Mp). They are obtained during the dry season (Table 2). The results show a decreasing gradient between the sites Mp and Me. The ammonium contents at the sites downstream of the plant are higher than those obtained upstream. Ammonium contents do not vary significantly ($p > 0.05$) between seasons at the sites P and Me.

Nitrates

Irrigation waters are characterized by low nitrate contents (<30 mg/L). The levels are higher during the rainy season. They vary from 1.42 ± 0.60 mg/L (site Me) to 28.68 ± 15.00 mg/L (site Me) respectively in the dry season and in the rainy season. The downstream levels of the textile factory are higher than upstream during the rainy season. All the average values of nitrate contents are significantly higher in the dry season ($p < 0.05$).

Table 2: Average values of the chemical parameters of irrigation water

Parameters	Seasons	Sites B	Sites Mp	Sites P	Sites Me	Irrigation standards
PO_4^{3-}(mg/L)	DS	0.008±0.01^{1a}	0.6±0.05^{4b}	0.49±0.19^{3a}	0.273±0.05^{2b}	2
	RS	0.017±0^{1a}	0.02±0.01^{1a}	0.29±0.08^{3a}	0.056±0.02^{2a}	
NH_4^+(mg/L)	DS	0.06±0.05^{2a}	3.53±0.33^{3b}	1.49±0.85^{1a}	1.18±0.34^{1a}	5
	RS	0.834±0.3^{1b}	0.98±0.24^{2a}	1.91±0.14^{2a}	1.008±0.44^{1a}	
NO_3^- (mg/L)	DS	4.48±2.56^{2a}	5.65±0.53^{2a}	2.12±9.4^{1a}	1.42±0.6^{1a}	30
	RS	13.71±5.75^{2b}	18.9±9.39^{1,2b}	27.74±9.4^{1b}	28.68±15^{1b}	
COD(mgO_2/L)	DS	99.7±35.4^{1b}	523.42±66.21^{3b}	124.85±85.73^{1,2a}	162.39±38.44^{2b}	-
	RS	47.46±6.28^{1a}	92.39±10.52^{1a}	269.52±194.01^{2a}	75.21±4.9^{1a}	

PO_4^{3-}: Orthophosphate ion; NH_4^+: Ammonium ion; **NO_3^-**: Nitrate ion; COD: Chemical demand for oxygen. DS: Dry season; RS: Rainy season. For each chemical parameter, the values with letters a and b in exponent show a significant difference ($p < 0.05$) between the seasons for the same site and those affected by the numbers 1, 2, 3 and 4 in exponent show a significant difference ($p < 0.05$) between sites for the same season.

Orthophosphates

The lowest levels of orthophosphates are obtained in the rainy season, with the exception of site B where the levels are similar over the two seasons. Also, the average values vary from 0.008 ± 0.01 mg/L (site B) to 0.605 ± 0.05mg/L (site Eb). They gradually decrease between sites Eb and Me in the dry season and they are very variable in the rainy season with a very low value in site Mp. At downstream sites of the plant, the content of orthophosphates is higher.

Chemical oxygen demand (COD)

The COD contents of irrigation water are very variable. The average values vary between 47.46 ± 6.28 mgO_2/L (site B) in the rainy season and 523.42 ± 66.21 mgO_2/L (site Mp) in the dry season. COD is higher in the dry season than in the rainy season, except for the site P. However, the downstream sites of the plant are more charged with COD. The average levels are significantly different.

3.1.3. Principal Component Analysis

Principal component analysis (PCA) was performed on the 10 variables and the 34 individuals (Figure 3a; Figure 3b). It enabled to assess the main parameters influencing the quality of irrigation water. The PCA shows that the first two axis F1 and F2 gather 84.93% of the total variance. In the correlation circle, the first axis explains 68.54% and the second axis 16.39% of this variance. Axis 1 is strongly correlated on the negative side by temperature, pH, ammonium, COD, TDS, conductivity and orthophosphate whose high values are noticed specially on the site Mp during the dry season then low values on site B. In contrast, on the positive side, it is defined by the redox potential, whose high values are found at site B and low or even negative values are noticed at the sites Mp, P and Me. The second axis is strongly correlated on the negative side only by turbidity and on the positive side by nitrate. The analysis of the projection of individuals in the F1-F2 factorial plan shows that we can subdivide the sampling points into three groups (Figure 3b):

- the first group I (site B) is characterized by low mineralization and low organic charge.
- the second group II (sites Me and P) has got accentuated medium mineralization.
- the third group III (Mp) site is characterized by a very high mineralization and a high organic charge.

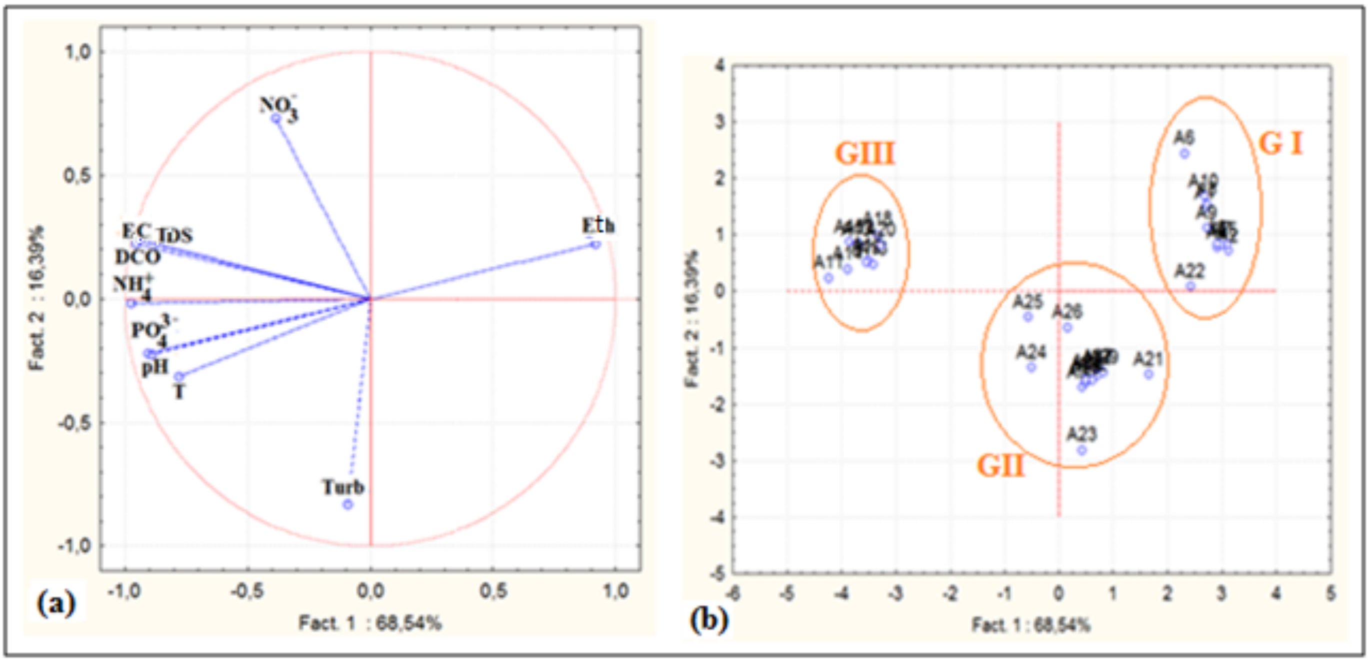

Figure 3: Projection of variables (a) and individuals (b) on axis F1 and F2

The correlation matrix between the various physico-chemical parameters determined in irrigation water is shown in Table 3. This matrix shows strongly significant correlations (r > 0,6) between conductivity, TDS, orthophosphates, ammonium, COD, temperature, redox potential and pH. The matrix also reveals a correlation between COD and nitrate (r = 0.52).

Table 3: Bravais-Pearson linear correlation coefficient r between the different physicochemical parameters

	T	pH	E_h	EC	TDS	Turb	PO_4^{3-}	NH_4^+	NO_3^-	COD
T	1.00*									
pH	0.79*	1.00*								
E_h	-0.80*	-0.99*	1.00*							
EC	0.60*	0.76*	-0.78*	1.00*						
TDS	0.60*	0.76*	-0.78*	1.00*	1.00*					
Turb	0.31	0.12	-0.14	-0.09	-0.09	1.00*				
PO_4^{3-}	0.65*	0.79*	-0.79*	0.80*	0.81*	0.33	1.00*			
NH_4^+	0.70*	0.85*	-0.86*	0.93*	0.93*	0.14	0.91*	1.00*		
NO_3^-	0.19	0.11	-0.12	0.49	0.49	-0.33	0,19	0.36	1.00*	
COD	0.65*	0.79*	-0.81*	0.96*	0.96*	-0.07	0.79*	0.92*	0.52*	1.00*

* significant value

3.2. Discussion

The study of the physico-chemical quality of the water resources near the Bouaké textile factory allowed us to characterize the irrigation water used for market gardening. The values obtained for certain parameters show the degradation of the quality of water resources, mainly the nearby area subject to direct discharges of factory effluent. The high values are encountered on the site Mp especially in the dry season. These high levels can be explained by the direct discharge of industrial wastes but also the anthropogenic activities that take place in the surroundings. Highest temperature values are recorded at the sites downstream of the textile factory and especially in February during the dry season. These high temperatures, also due to strong sunny weather, could increase the rates of chemical and biochemical reactions [23, 24]. Increase of temperature leads to decrease in the dissolved oxygen (DO) content, which is very essential for the survival of the aquatic system, reduction in crop growth, and deleterious effects on aquatic organisms [25]. On all the sites located downstream from the textile factory, the values of the redox potential are negative, so that environment is reducing and eutrophic [26]. This would confirm the insufficient dissolved oxygen in that environment [27] and would show a high organic charge due to discharges from the textile factory [28]. The pH values are relatively high (between 8 and 12) at the level of sampling sites close to and downstream of industrial textile discharges, especially in the dry season. The raw effluent-water mixture from the dam is very alkaline in the dry season with an average pH value of around 12. These high pH values could be explained by the small amount of water from the dam flowing into the raw effluent which would be very alkaline. Indeed, diluted water from the dam would not be sufficient to significantly impact the pH of the raw effluent. pH values greater than 10 were obtained by [29] and by [30]. Those people attributed the high pH values to the use of detergents and soda used in the manufacturing processes of textile. pH values obtained at the sites Eb, Mp and Me do not meet the quality criteria for water used for irrigation (6.5 – 8.4) [5]. The conductivity values obtained indicate an average mineralization of water of site B and an accentuated mineralization in water of the sites P and Me. In terms of salinity, water of those sites is suitable for irrigation according to [5] which sets the standard at 3000 µS/cm. However, very high values of conductivity are noticed at the site Mp in dry season. This could be explained by the origins of water flowing into dam water, which is mainly of anthropogenic origin (discharges of untreated industrial effluents and domestic wastewater). [31] believes that the increase in conductivity is also due to the concentration of mineral salts in water by evaporation and the increase in alkalinity. Therefore, the reuse of these waters could have adverse effects on agriculture [30]. During the rainy season, low values of conductivity are recorded. This observation would probably be due to the dilution effect caused by heavy rainfall [28]. In the dry season, on the site Mp, our values are close to those of [32], with a conductivity of around 9565µS/cm. Whereas, they are considerably higher than those measured by [9, 33]. These high conductivity values can cause the salinity problem. This would lead to undesirable effects on both physical properties of the soil and on the growth and quality of crop productivity [34]. During the dry season, the conductivities of all water taken from the site Mp exceed the acceptable limits according to [5]. PCA enabled to establish correlations (positive or negative) between the variables. On axis 1, pH, conductivity, temperature, TDS, ammonium, orthophosphate and COD are negatively correlated. These results obtained are similar to those of [35] and [36] who argued that that axis expresses both mineralization and organic pollution due to conductivity, ammonium, orthophosphate, the COD of water. As for the parameters quoted above, they showed that only the measurement of the electrical conductivity could therefore be sufficient to predict the quality of water. However, the redox potential alone contributes on the positive side to express that axis. The expressed variance rate (84.93%) is higher than that of [36] and of [37] who reported respectively 69.77% and 55.36% of total variance in Lake Oubéira in Algeria and in the Doba oil basin in Chad and lower than that found by HANE in well and borehole water in Senegal with a variance of 99.9% [38]. Along with conductivity, the TDS values do not meet the water quality standards used for irrigating at the site Mp in dry season. COD values are high at that site especially in the dry season. Similar tendencies were encountered by [30] in Madagascar and by [39, 9] in India and by [30]. However, [29] found lower values in Togo. Our results show that waters of the site Mp are highly charged with biodegradable and non-biodegradable organic matter (COD) during the dry season, exceeding the expected discharge value set at 500 mgO_2/L by the [40] and Ivorian standards [15].

According to [31, 25], that situation could have adverse effects on water quality (decrease in oxygen quantity) in general and on the aquatic ecosystem in particular. Measurements of the redox potential on this site confirm that existence of organic substances with very low values recorded, even negative. Indeed, the origins of that rise in COD at the site Mp level may be due to inputs of organic matter from industrial and domestic wastewater (dyes, paint, oils, etc.) coming from the textile factory or from neighboring agglomerations areas evacuated by the sewage system. From the site Mp, the general change in COD shows a decreasing gradient going from upstream to downstream. That may be caused by physical phenomena such as settling and as a result could reduce their content at the water level on the sites P and Me [31]. Irrigation water is generally slightly cloudy (NTU>5) and the turbidity values are higher during the rainy season at all sampling sites. This fact would be due to the high concentration of undissolved suspended matter coming from discharges of the textile factory [29] and to the leaching of agricultural land by runoff water but also to organic particles such as degraded animal and plant materials. That could lead to clogging of the soil, the consequences of which are harmful for crops [41, 25]. The spatio-temporal evolution of the orthophosphates and ammonium concentration indicates a decreasing gradient starting from the site Mp to the site Me. That reduction in the water downstream of the textile effluent would be due to their assimilation by photosynthesis of algae. That happens because of the eutrophication phenomenon which replaces self-purification when the ecosystem is enriched with carbon dioxide, ammonium ion and orthophosphates [42]. According to [39], orthophosphates play a primary role in the eutrophication process, a phenomenon with environmental (algal development) and health (release of algal toxins) consequences. The phosphate content in water can lead to kidney damage and osteoporosis in human [39]. In addition, seasonal variation shows that the levels generally decrease from the dry season to the rainy season, outside site B. That variation could be explained on the one hand by the phenomenon of dilution of orthophosphates and ammonium during the rainy season, and on the other hand by the oxygenation of the water, causing the oxidation of ammonium. For [31], those two phenomena are responsible for the low ammonium ion contents observed during the wet period. Unlike orthophosphate and ammonium, nitrates are higher in the rainy season. That could be due to leaching by rains of agricultural land in the watershed, pouring domestic waste from neighboring living places and excrement from livestock (cattle) into the studied waters [43, 23]. That temporal evolution of nitrates was also noticed in the work of [44] and [44,45].

Conclusion

At the end of this study, it clearly appears that the physico-chemical quality of water resources is strongly influenced globally by anthropogenic activities and particularly by industrial discharges. The comparison of the different results obtained from analyzed water reveals the degradation of irrigation water downstream of the discharges just from the textile factory. Thus, the effluent from the textile factory contributes significantly to the degradation of the quality of water downstream. Because of their salinity, they are not of good quality for irrigation. The site Mp characterized by a strong alkalinity, a high mineral and organic load especially during the dry season is the most affected. The negative impact of textile effluents on the quality of downstream water was proved. Thus, textile factory effluents require prior treatment before being released into the environment. The application of the principal component analysis on these results shows that we have three groups of stations, one group with low mineralization and organic charge downstream of the textile factory, another with an accentuated medium mineralization, and finally the third group with a very high mineralization and an important organic charge.

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