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Physico-Chemical characterization of the surface water of Nkam River using the Principal Component Analysis

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- Nkam River

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Abstract

The study concerns the analysis of physico-chemical parameters of the Nkam river in order to establish a diagnostic of water surface status of the river. To carry out the study, samplings were carried out on 12 stations during the dry season. The results obtained shows that at stations level (S1 to S7) where wastewater discharge from the villages situated along the river, the water has relatively good quality compared to international standards for fresh water (WHO), starting from temperature, salinity, electrical conductivity through TDS to DBO_5 and PO_4^{3-}. A rise in dissolved oxygen level, BOD_5, PO_4^{3-}, salinity and electrical conductivity downstream (S9 to S12) particularly in the dry season was observed. Furthermore, the evolution of pH doesn't vary considerably between upstream and downstream in dry season. Data interpretation performed by Principal Component Analysis (PCA) showed the correlation between the different parameters and the stations group distribution according to the degree of contamination. Potentially interesting modeling parameters are identified using this statistical data processing tool.

1. Introduction

Renewable fresh water is an indispensable resource for life. This is why it deserves special attention because it is very impaired and seriously threatened by human activities. In fact, population growth accompanied by rapid urbanization causes many disturbances for natural environments [1-4], industrialization, the non-rational use of fertilizers and pesticides, and the lack of public awareness of the protection of the environment, lead to an imbalance of the ecosystem and generate pollutants that can affect the physicochemical and biological quality of aquatic receptors [5-8], but also alter the uses of water (capture Water, bathing, etc.) [9]. For a good characterization of the river, it would be advisable to study it on three axes namely: physicochemical study, granulometry and lithology. The case in point is that of the river NKAM located in the forest zone of the west and the littoral Cameroon. This former port and commercial square in the south of Cameroon enjoyed its glory during the colonial era. The Nkam River originates in West Cameroon and flows to Douala in the Wouri River [10]; The upstream zone is an area full of wildlife, flora and forest resources that are under enormous pressure following the contact of the waters with the Wouri River, which is often polluted by industrial waste, ballast water and all forms of waste from Boats [10]. We note that these wealth possessed by the river Nkam are evacuated to the large urban centers (West, Center and especially the Littoral Cameroon) Yabassi which presents itself as a hub. It is still at the crossroads of many projects since it is endowed with the river Nkam which constitutes its biggest access road. However, the inadequacy of a recent database on physico-chemical characteristics constitutes a barrier to the exploitation of natural resources such as water in order to increase agricultural or aquacultural production in the department in particular and the Cameroonian coastal region in general. The objective of this work is to measure the physicochemical parameters of the Nkam river waters in situ and in the laboratory and to use the principal analysis components to mainly understand the quality of the waters of the river and the ecological states of the environments studied [11].

2. Presentation of the study area

The Nkam River flows in a north-east / south-west direction. It rises on the slopes of Mount Ekomane north of Mount Manengouba. From the left bank, it receives the waters of the Menoua, the Metchie and the Ngou, coming from the flanks of the Bamboutos Mountains and following an average slope of about 3°. At the confluence with the Makombe, it takes on wingspan as its slope of flow decreases. Its entry into the coastal sedimentary basin is marked by rapids upstream of Yabassi. Downstream of these rapids the river grows; especially as it receives the waters of the Dibombé, its main tributary of the right bank. It thus becomes navigable to the immense estuary of Wouri where the port of Douala was laid out. The relief in the Nkam appears as a succession of small narrow valleys, hills and shallows. This relief favors the enclavement of this area thus making the accessibility very difficult [13]. The relief is undulating. It is formed by an arrangement of plains, deep valleys such as Lambda and plateaus. The altitude varies from 10 m in the plain to about 700 to 800 m in the North-East and North zone. In terms of hydrography and climate, apart from the Nkam river which becomes the Wouri downstream and extends over a periodic coastal plain, the Yabassi district is densely watered by many other rivers such as: The Dibamba, the Makombe, the Njanga, the Mahe. The climate is characterized by high humidity. The temperature generally varies between 23°C and 29°C. The dry season runs from mid-November to mid-March. The hottest month is February. The District of Yabassi is very rainy such as the department of Nkam. The annual rainfall heights are between 2900 and 3000 mm.

3. Materials and methods

The study was carried out in the coastal region, Nkam County, Yabassi District. From Yabassi township to Bodiman observation stations which geographical coordinates was previously identified. The average altitude of stations which varies between 15 to 20 m corresponds to the Nkam valley. Taking into account the various activities identified in the study area (domestic wastewater, discharges of all types of waste and agricultural practice in the area), twelve water samples were collected by a Van Dorn bottle of polyvinyl chloride at twelve sites along the Nkam River (Figure 1). Details of the location of surface water sampling as well as their longitude and latitude are presented in Table 1. These sites have been selected in such a way that they are accessible and reflect the actual characteristics of Nkam River surface water at the study area. Along the Nkam River and throughout the study area, water samples were collected in 2014 during the dry period.

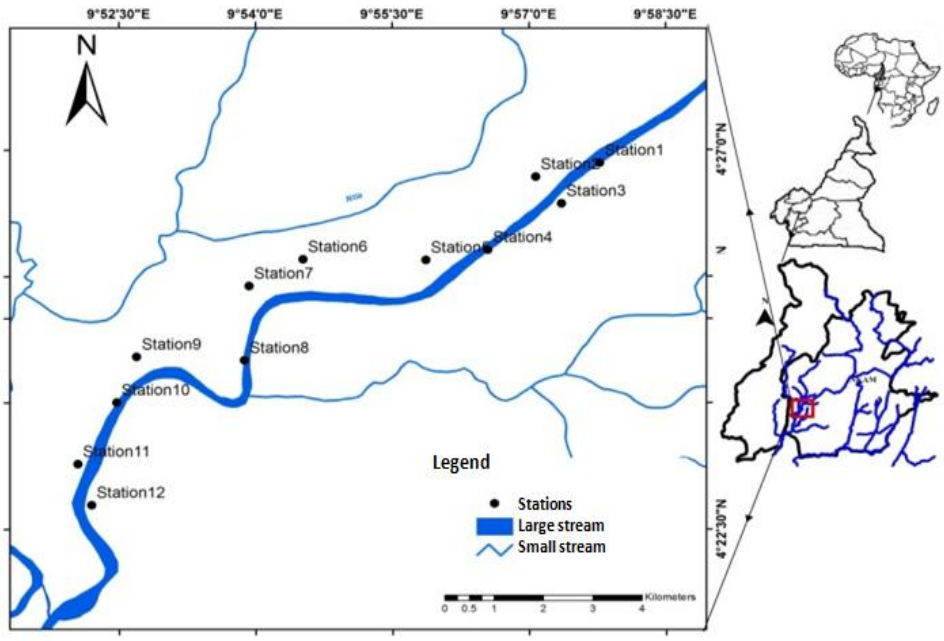

Figure 1: Sampling sites on the Nkam River [12]

Table 1: Geographical coordinates of the stations

Stations	Villages	Latitude	Longitude
1	Ndokbèlé	4°22'9,92°N	9°52'28,76°E
2	Titina	4°22'39,68°N	9°52'7,29°E
3	Bonalembé	4°23'27,80°N	9°52'21,91°E
4	Bonakata	4°24'22,73°N	9°25'58,72°E
5	Bonanyama	4°23'55,16°N	9°53'52,04°E
6	Bonabondo	4°24'58,69°N	9°54'2,83°E
7	Bonakaté	4°25'15,03°N	9°55'41,58°E
8	Bonadjend	4°25'59,68°N	9°56'48,27°E
9	Bonapendè	4°25'80,52°N	9°56'39,26°E
10	Bwemba	4°26'59,30°N	9°56'23,77°E
11	Bonassombendé	4°26'71,02°N	9°56'23,79°E
12	Bonanyamsi	4°27'9,90N	9°56'28,70°E

3.1 *Field measurement*

The physico-chemical parameters measured are: Water temperature, Total Dissolved Solids (TDS), electrical conductivity, salinity, hydrogen potential (pH), BOD_5 (biochemical oxygen demand), dissolved Oxygen, Orthophosphates (PO_4^{2-}), nitrate (NO_3^-). At each sampling, the measurements carried out in-situ are: water temperature, air temperature, electrical conductivity, salinity, pH and dissolved oxygen via a boat equipped with several devices including a GPS, a conductivity meter, a thermometer, a pH meter, an oximeter, a timer, a multi parameter device. The temperature and the hydrogen potential were determined by a Hanna HI 9024 type pH meter equipped with a temperature sensor. The electrical conductivity was measured by a Hanna HI 8733 conductimeter. Water samples were transferred to the laboratory for physical and chemical analysis.

3.2 *Laboratory analyzes*

The water samples were taken using sampling bottles, previously rinsed with station water and transferred to labeled glass bottles. They were then stored at 4°C during transport to the laboratory and analyzed within 24 hours. The methods of analysis are those recommended by the standards AFNOR [14], and by Rodier [15,16]. Orthophosphates and nitrates were assayed spectrophotometrically. The chemical oxygen demand is determined by adopting the standardized method AFNOR (T90-101). The biochemical demand was measured using a BOD meter. Determination of dissolved oxygen was also carried out in the laboratory after fixation of the oxygen in the sample by the Winkler titration method. The statistical approach to analyzing water quality data was based on PCA. The intermediate correlation matrices, the correlations between the variables, the axes and the projection of the variables in the axes space F1 and F2 were obtained with the PAST3 software. However, there are three other approaches that can be used to assess the quality of a water body: (1) the index approach, (2) the trophic approach of the state index, (3) Approaches through biological analyzes such as the Genetic Algorithm Method and other biological indices [17]. Principal component analysis is a purely mathematical technique without any postulate. The results of the analysis of the main components show that it provides reliable information relative to observations in the fields of scientific research [18].

4. Résults and discussion

4.1 Descriptive analysis

4.1.1 Temperature

Measuring temperature is essential to understanding the biological, chemical and mineralogical processes that develop in a river. It allows scientists to better understand other hydrological measurements such as dissolved oxygen, pH and conductivity. In the study area, recorded temperatures (Figure 2) oscillate between 26.41°C (station S2) and 30.24°C (stations S9) for ambient temperature, and between 25.80°C (stations S3) And 29°C (stations S8 and S9) in terms of surface temperature.

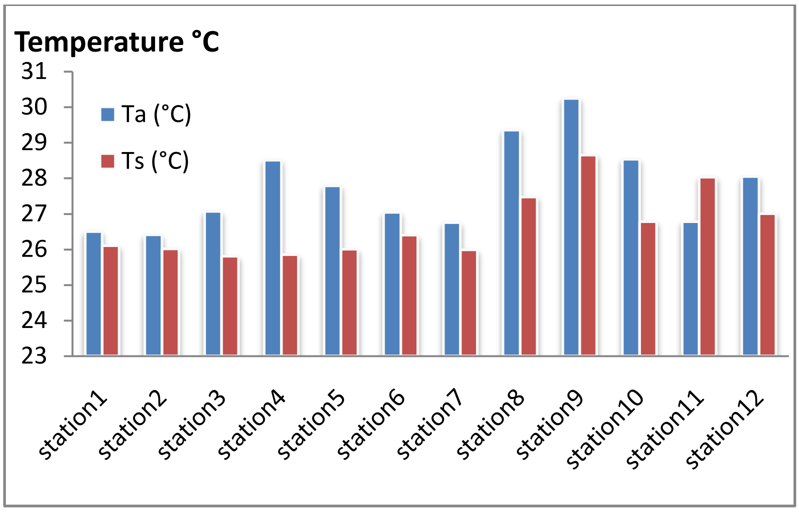

Figure 2: Spatio-temporal variation of temperature

Temperature variations follow the climate of the region. Temperatures measured on surface waters of the Nkam river therefore belong to the middle class according to Douala OBS, 2010. An increase in temperature strongly imbalances the environment, but may also be a factor in the increase in biological productivity [19]. A high water temperature can be fatal to some species such as trout or salmon, which require cold water and high oxygen. The hotter the water, the less dissolved oxygen it contains. The temperature of the water does not change at the same speed as that of the air: it cools less quickly. Indeed, water has a higher thermal capacity than that of air. The processes of evaporation and condensation of water also play a role in the change of air temperature. Finally, it is important to know the water temperature in order to understand the different climate scenarios at the local and global scale. Temperature influences the quantity and diversity of aquatic life. The rise in water temperature at the arrival of the small dry season is followed by rapid growth of plants and microscopic aquatic animals. Many fish and other aquatic animals breed at this time of year because they have warmer waters and abundant foods.

4.1.2 *Salinity*

Temperature and salinity are the main abiotic factors essential for the physiology of fish [20]. Salinity is a parameter that depends on the volumes of fresh water and seawater introduced into the medium causing longitudinal variations of the contents. In the Nkam River, salinity varies between 34.5 (S1) and 57.74 ppm (S5) (Figure 3) for low levels upstream (Yabassi township). It varies between 134 (S9) and 185,24 ppm (S10) downstream (Canton Bodiman). Salinity also influences the density of water causing a second vertical and leading a stratification gradient of water (mainly in the vicinity of the salinity front). Like temperature, salinity is a parameter dependent on large-scale phenomena (Eg floods and retreats associated with a rise in water level or a decrease in continental intakes). Salinity is a parameter that conditions the range of living species in an environment according to their preferendum (excluding euryhaline species with high salinity amplitudes). If salinity varies, the survival of organisms will depend on their tolerance.

4.1.3 *Total dissolved solids*

The ion concentrations observed in the waters of the Nkam River (Figure 4) range from 30.3 ppm (S1) to 203.87 ppm (S10, S11 and S12) during the dry period (flood recession). The minimum values are recorded in the upstream part of our stations starting from Yabassi and the maximum values are observed at the stations (S10, S11 and S12) located respectively downstream in the Bodiman township. This evolution indicates the contribution of anthropogenic input, which may be of agricultural origin, or come from the elements trapped in the sediments somewhat more present downstream, or because of the proximity with the Wouri waters. For this study period, the contents are below the standards set at 750 mg/l [21]. This makes it possible to classify these waters in the grid of very good (S1 to S7) to good (S8 to S12) of the surface waters. High levels of this element in surface waters can lead to eutrophication in the long term. For domestic use, water preferably has a TDS of less than 500 ppm, although water with a higher TDS is not a major hazard. Water used in agriculture must have a TDS of less than 1200 ppm so that fragile crops are not damaged. For industry, and especially for the electronics industry, pure water is needed. These results show that the Nkam waters are of medium to excellent quality [21].

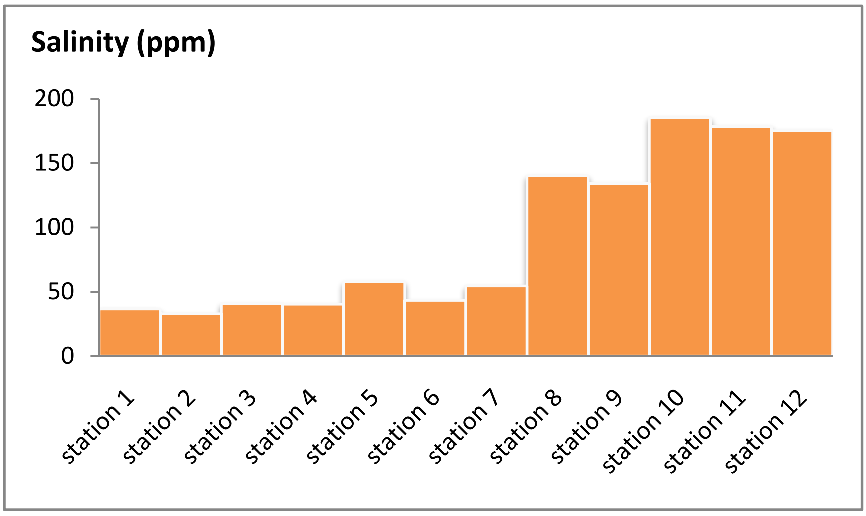

Figure 3: Spatio-temporal variation of the salinity

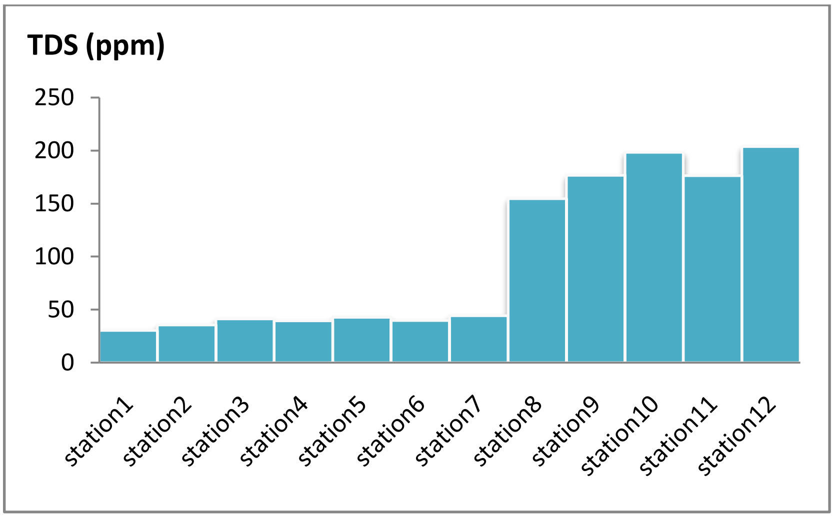

Figure 4: Spatio-temporal variation of Total dissolved solids

4.1.4 *Hydrogen Potential*

The pH has values comparable to those found in most coastal Cameroonian waters subjected to anthropogenic stress [10]. The observed and revealed values show that the pH in the Nkam River is slightly acid upstream (S1, S2, S3, S4, S5, S6, S7), whereas, from the S7 station, the pH is substantially neutral to alkaline, during dry periods. Indeed, the pH varies between 6.55 in station S1 and 7.15 in station S10. This is due to the presence of carbonates that buffer the waters flowing to the Wouri River, streaming and infiltrating the maro-dolomitic and limestone cover.

The variation of the pH between the two cantons exceeds substantially one unit of the pH and the appearance of the curves (Figure 5) is very variable and does not follow a regular law. Indeed, pH tends to increase from upstream S1 downstream station S10 to its maximum value in station S11, which can be explained by contact with the waters of the Wouri River or by the leaching of waters from agricultural areas along the banks of the Nkam River. Subsequently the pH stabilizes towards neutrality immediately.

4.1.5 *Electrical conductivity*

They fluctuate between 47.2 µS/cm at station S1 and 230.25µs/cm at station S11 during dry periods in Nkam surface waters, indicating low mineralization attributed to Nkam waters (Figure 6). It can also be explained by the presence of a large quantity of ions in the surface water layer starting from station S8 to S12. The values of the conductivity obtained coincide with those of most of the coastal waters of the coastal region already studied [18]. The mean values of the conductivity of stations S1 to S7 are relatively higher than those of S8 to S12 due to the decomposition of organic matter and soil fertilizers.

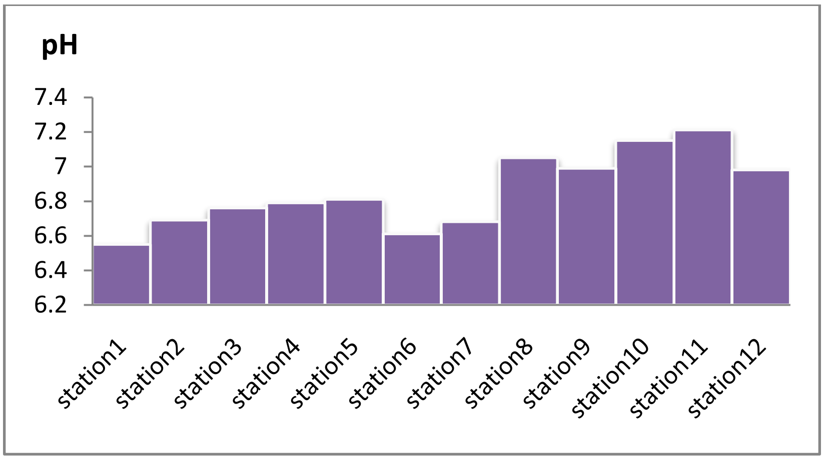

Figure 5: Spatio-temporal variation of pH

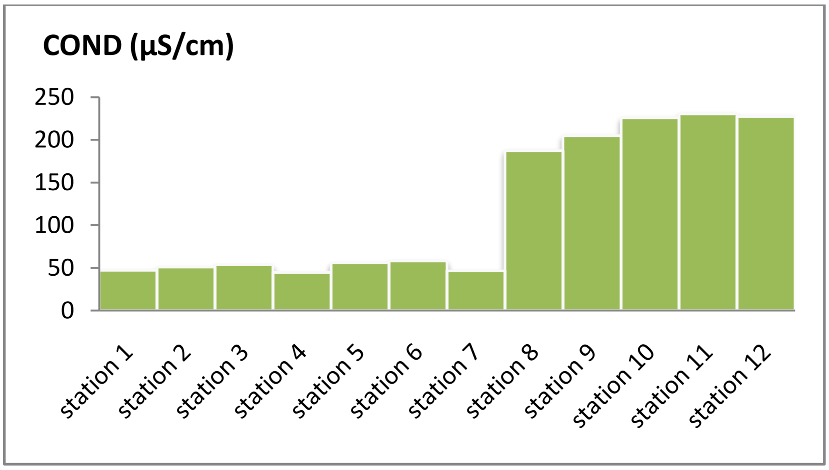

Figure 6: Spatio-temporal variation of conductivity

4.1.6 *Dissolved oxygen*

The thermal regime of the river is closely correlated with the quantity of oxygen dissolved in the water [22]. During the dry season, the warming of the water and the low flow of the Nkam cause a decrease in the dissolved dissolved oxygen, aggravated by an increase in the consumption of oxygen by living organisms in the Nkam river and a fall of wind speed. Indeed, the mineralization of biomass photosynthesis and the respiration of planktonic populations influence the oxygen content in water [23]. The low dissolved oxygen levels observed in dry periods at stations (S3) and (S11) may be due to the presence of the animal organisms in Figure 7.

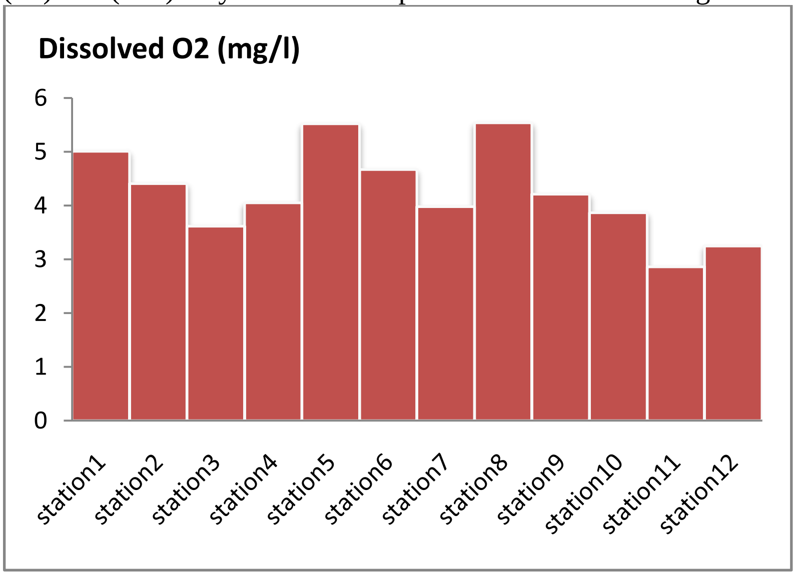

Figure 7: Spatio-temporal variation of dissolved oxygen

The dissolved oxygen is reduced by the activity of the bacteria by decomposing the organic matter present. Overall, the dissolved oxygen regime in the study area is non-deficit; the phenomenon of self-purification takes place which makes it possible to enrich the level of dissolved oxygen. These results show that the Nkam waters are from medium to excellent quality [21].

4.1.7 *Biochemical oxygen demand*

Oxidation of biodegradable organic materials is closely linked to biochemical oxygen demand (BOD). Figure 8 shows an increase in the BOD_5 of the Nkam waters from upstream to downstream, especially during dry periods. The average BOD_5 values range from 0.23 mg/l (S1) to 0.84 mg/l (S6) and between 1.21 mg/l (S8) and 2.54 mg/l (S12) in dry periods. The increase in BOD_5 levels from upstream to downstream may be explained by the introduction of the degradation conditions of the organic matter by the microorganisms whose activity intensifies with the decrease in flow velocity and with the warming of the waters. This activity, consuming oxygen, is at the origin of the self-purification of the waters [24, 25]. However, in rainy weather, rainwater contributes to the dilution of the organic load.

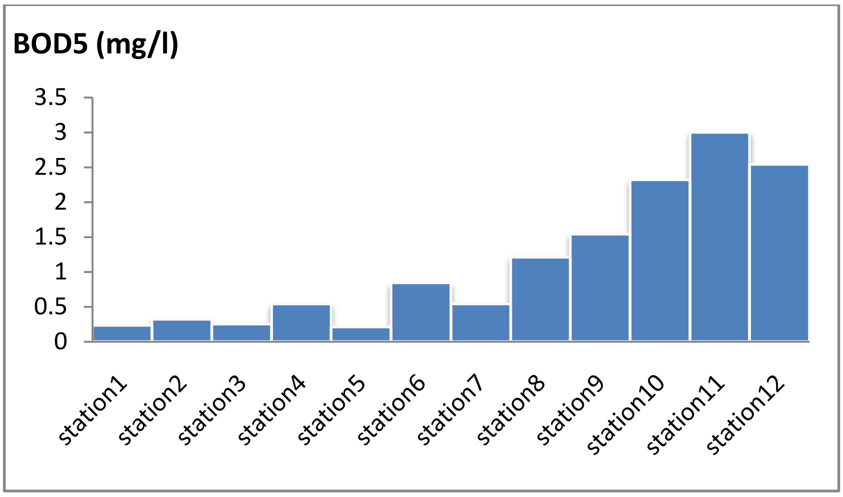

Figure 8: Spatio-temporal variation of biochemical oxygen demand

4.1.8 *Orthophosphates*

Algae exploit mineral phosphorus either by altering various organic phosphates or in the form of orthophosphates by absorbing it immediately. Enzymes called alkaline and acid phosphatases are grown by algae to hydrolyze organic phosphates and remove assimilable mineral orthophosphate. Analysis of the results (Figure 9) shows that the concentration of Orthophosphates in Nkam surface waters ranges from 0.015mg/l (S1) to 0.315mg/l (S9) in the dry season.

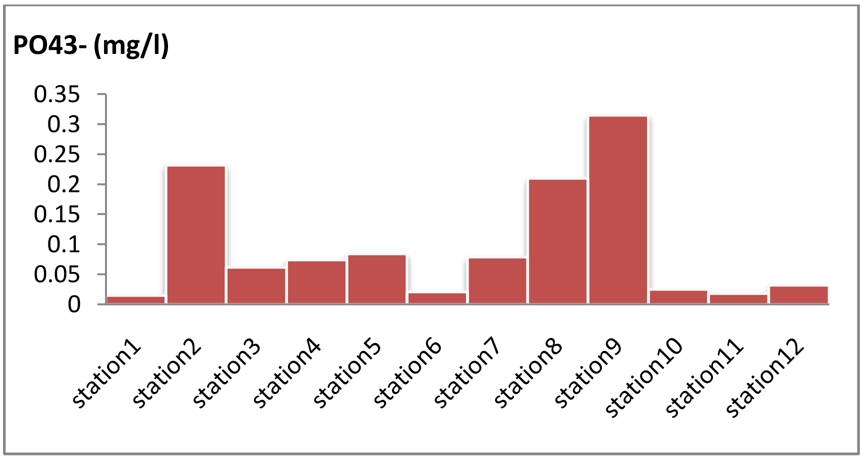

Figure 9: Spatio-temporal variation of Orthophosphates

At the level of the upstream sector (from S1 to S6), the levels of Orthophosphates are low except at the station (S2) and are less than 1 mg/1 for the Nkam waters. However, in the downstream sector (from S8 to S12), Orthophosphates follow a relatively marked spatial variation by a tendency to increase in dry periods. This availability of Orthophosphates can be explained by the presence of agricultural areas all around the study site, as well as the presence of the discharge at Wonde and the release of phosphorus trapped in large quantities in the sediments [26, 27].

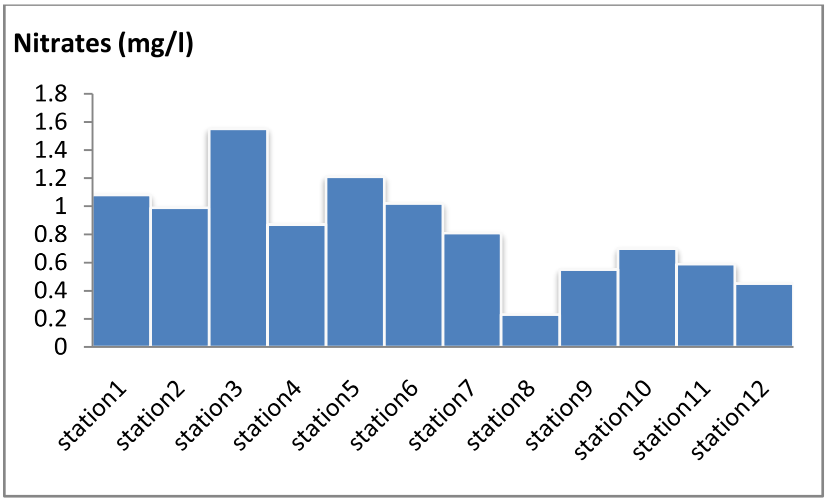

Figure 10: Spatio-temporal variation of nitrates

The phosphates returned to the environment are mainly derived from industrial, agricultural (fertilizer) sources, excreta, etc. Atmospheric agents, such as wind and rain also represent sources of phosphates, especially when river flow is low (Holden Martin, 1980). As in the downstream waters of the river, enrichment was noted in the downstream sector (S8 to S12), but these concentrations remain below the global norm set at 1 mg/l. These values then make it possible to classify these waters from good class (S1 to S7) of excellent quality (S8 to S13) [21].

4.1.9 *Nitrates*

Water nitrates result from the oxidation of ammoniacal nitrogen and nitrites and the mineralization of the river biomass. The values recorded in the histogram of nitrate contents in Nkam waters (Figure 10) show a slight variation in these levels, which range from 0.23 mg/l (S8) to 1.55 mg/l (S3) during dry periods. The increase in nitrate levels may be due to the leaching of fertilizers used in agricultural soils along the river. Low values recorded during the dry season could be attributed to agricultural plantations or to the presence of the wave discharge and low levels of dissolved oxygen since nitrates represent the most oxygenated form of nitrogen and can play during period of low oxygenation the role of oxygen donor, thus avoiding anaerobiosis. Nitrate levels recorded in the surface waters of the Nkam River are very low compared to the levels suggested by international standards (50 mg/l). This indicates that the waters studied are not subject to a risk of nitrate pollution and therefore of very good quality.

4.2 *Statistical data processing*

The principal component analysis (PCA) for interpreting hydrochemical data [28, 30] allows a large number of variables to be processed simultaneously in order to establish a relationship between the various physico-chemical parameters, stations and phenomena at the origin of these relationships such as anthropogenic activities along the Nkam River. The PCA provides the opportunity to reduce the number of variables to be considered in the study of aquatic environments [30, 31]. For data processing using principal component analysis, we used a matrix of 10 variables and 12 stations along the river.

The correlation matrix (Table 2) shows the relationships between the various parameters such as surface water temperature, air temperature, dissolved solids (TDS), electrical conductivity, salinity, the potential of hydrogen (pH), BOD_5 (biochemical oxygen demand), dissolved Oxygen, Orthophosphates (PO_4^{2-}) and nitrate (NO_3^-). All linear correlations are not always positive (meaning that the variables evolve in different directions), some being too strong (0.99 and 0.90), other means (0.66 and 0.61) and others still quite weak (0.27 and 0.01).

Each factorial corresponds to a percentage of the explained variance and an eigenvalue of the correlation matrix. The analysis of the first factor plane F1 and F2 (Table 3 and Figure 11) show that over 99.1488% of the variables are expressed. This explains why the first two axes are sufficient to reproduce the information in its entirety. The F1 axis has a variance of 98,123%, expressed as air temperature, pH, TDS, electrical conductivity, salinity, dissolved oxygen, nitrate, ortophosphate and biochemical oxygen demand has strong correlations: TDS and electrical conductivity (0.99), TDS and salinity (0.98), electrical conductivity and salinity (0.98). The axis F2 which has a variance equal to 1.0258% is constituted by the surface temperatures.

Table 2: Matrix of correlation between the different variables

	Ta (°C)	Ts (°C)	TDS (ppm)	COND (µS/cm)	Salinity (ppm)	pH	O^2 dissolved (mg/l)	Nitrates (mg/l)	PO_4^{2-} (mg/l)	DBO_5 (mg/l)
Ta (°C)	1,00									
Ts (°C)	**0,99**	1,00								
TDS (ppm)	**-0,70**	**-0,71**	1,00							
COND (µS/cm)	**-0,71**	**-0,72**	**0,99**	1,00						
Salinity (ppm)	**-0,77**	**-0,78**	**0,98**	**0,98**	1,00					
pH	**-0,66**	**-0,68**	**0,89**	**0,90**	**0,92**	1,00				
O_2 dissolved (mg/l)	**0,61**	**0,60**	-0,26	-0,27	-0,27	-0,17	1,00			
Nitrates (mg/l)	0,37	0,38	-0,77	-0,76	**-0,74**	**-0,65**	-0,01	1,00		
PO_4^{2-} (mg/l)	0,48	0,48	0,12	0,11	0,00	0,10	0,44	-0,30	1,00	
BOD_5 (mg/l)	**-0,86**	**-0,87**	**0,91**	**0,92**	**0,93**	**0,84**	-0,48	**-0,68**	-0,15	1,00

Table 3: Correlation between variables and factors

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
Eigenvalue	191000,00	1999,50	475,66	259,77	17,61	2,85	1,76	0,64	0,13	0,02
Variance %	98,12	1,03	0,24	0,13	0,01	0,00	0,00	0,00	0,00	0,00

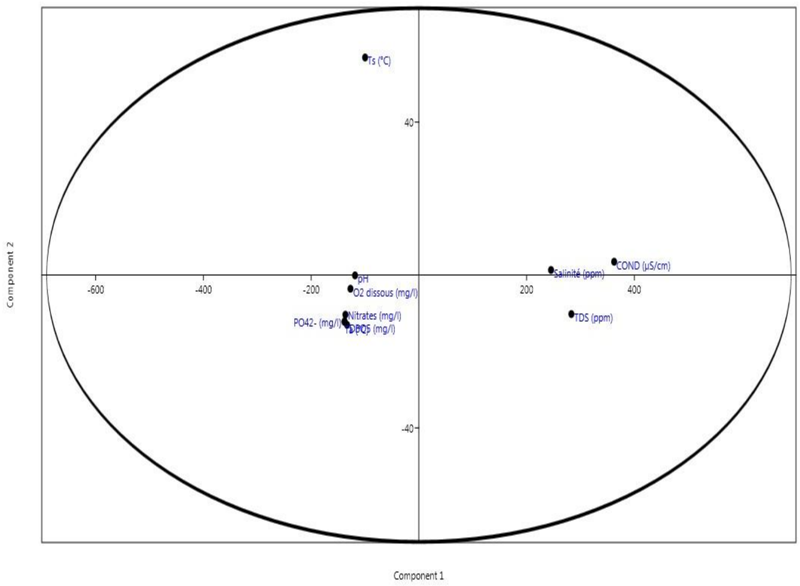

Figure 11: Projection of variables on the first factorial plane

The F1 axis, which represents 98,123% of the total inertia, indicates the highly rich mineralized waters in very good condition and the weakly worn waters. Variables such as BOD_5, NH_4^+ et PO_4^{3-} are indicators of domestic pollution from dissolved oxygen. The position of dissolved oxygen, BOD_5, NH_4^+ et PO_4^{3-} on the negative part of component 1 could be justified by the fact that the waters of the Nkam river are less oxygenated in the downstream part in contact with effluent impacts, the waters of the Wouri estuary and also runoff due to leaching of agricultural waters from riparian plantations downstream of the river in the Bodiman township. The axis 2 (1.0258%) is associated with the surface temperature. It defines a meteorological axis that essentially affects the external space of the milieu.

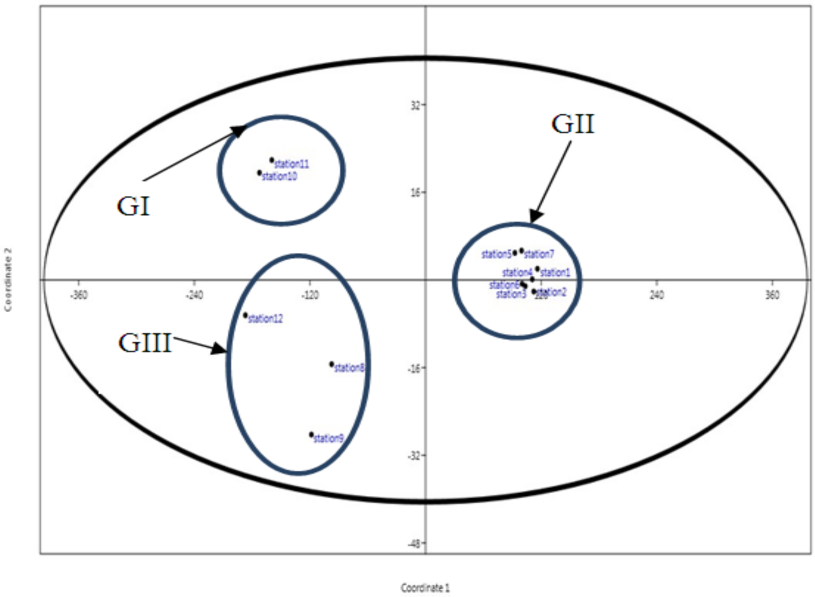

Figure 12: Projection of individuals on the first factorial plane

The global analysis allows defining a typology of the waters of the ecosystem dominated by three groups of stations GI, GII and GIII (Figure 12). The GI group, which includes the stations situated upstream of the study area (S1 to S7), characterizes the stations with very good quality of water but rich in nitrates. The group GII is represented by the stations located between the two extremities (S10 and S11) with an average water quality affected by the organic pollution. These stations should be loaded with organic pollutants during the dry period. This area is located at the entrance of Bodiman Township. The group GIII is represented by the stations (S12, S8 and S9) located inside the Bodiman township comprises the majority of the stations characterized by the presence of the plantations on both banks of the river with tributaries coming from the anthropized zones.

Conclusion

The downstream part of the Nkam river is subjected to discharges of waste water from agricultural areas at stations S8, S10 and S12 respectively. However, the physico-chemical parameters studied remain compatible with feeding water standards for the farming of fish, frogs, algae, all in cages. The Principal Component Analysis of the physico-chemical data allowed us to highlight the existing correlation between the different parameters and to differentiate a zonality from the water quality in the study area. Wastewater discharges, domestic waste dumps, industrial waste from the Wouri River, nitrification are the main causes of variations in water quality in the NKAM River. The limited number of data, frequency of observation, errors in the analysis of the quality of variables in the laboratory or in situ, and the unavailability of information on all activities in this region may contribute to difficulties in interpreting the principal components analysis. It would be essential to assess the effect of seasonal variation, frequency of observation on changes in water quality in view of the sustainable use of this ecosystem.

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