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RESEARCH ARTICLE

PHYSICO-CHEMICAL CHARACTERIZATION OF THE SURFACE WATER IN THE LOWER VALLEY OF THE OUEME IN SOUTH BENIN

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Abstract

Surface water in the lower Ouémé valley is prone to various pressures from anthropogenic activities as well as poor hygiene practices that favour its pollution. The present research aims to study the physicochemical quality of surface waters. Thus, seven (07) sampling sites have been selected with eighteen (18) parameters analysed. These are variables such as: hydrogen potential, temperature, electrical conductivity, dissolved oxygen, turbidity, suspended matter, calcium, magnesium, potassium, ammonium, nitrates, ortho-phosphates, chloride, sulphates, sodium, COD and BOD5 during high and low waters. The data were then processed through the Water Quality Assessment System (SEQ-Water) to determine the overall water quality. Similarly, Principal Component Analysis (PCA) is used to assess the relationships between the variables studied and their spatial distribution. The results show that during the two periods, surface waters are of "very good quality" 47.06% and 52.94%, of "good quality" 41.18% and 11.76%, of "fair quality" 17.65% observed only in low waters, of "poor quality" 5.88% and 11.76% and finally of "very poor quality" with 5.88%. As for the multivariate statistical study carried out through the PCA, it indicates the strong positive correlation of the variables NH4+, Na+, Cl-, CE and SO42- in periods of low water as well as the variables Mg2+ and T° strongly correlated in high water. Wastewater discharges, agricultural activities and poor hygiene practices are the main cause of water pollution.

Introduction:-

Surface water resources are increasingly prone to pollution, with the result that the quality of the water is deteriorating due to the increase in the number of sources of contamination. Anthropogenic activities of a socio-economic nature coupled with those of natural processes (soil erosion, precipitation, evaporation, river water runoff) accelerate the degradation of surface water resources (Aw et al., 2011). Indeed, water quality monitoring is a function of time and space. According to Aguiza et al. (2014), water quality evolves with the

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seasons and from one region to another, even in the absence of pollution. As a result, surface water quality is deteriorating and has become a global concern (Tohouri et al., 2017). However, water pollution in developing countries is often due to anthropogenic activities as a result of uncontrollable urbanisation with the frequent absence of appropriate wastewater treatment and direct discharge into the natural environment (Youmbi et al., 2013).

In Benin, several studies have focused on the pollution of rivers and water bodies. According to (Akognonbé, 2014), fishing practices such as the use of hydrocarbon fishing gear and associated mechanical interventions have contributed to the direct pollution of rivers and water bodies. Djèdjiho et al (2014) in their work, pointed out the pollution of Lake Ahémé-Gbézounmè due to strong mineralisation with the corollary appearance and proliferation of macrophytes and phytoplankton. This vulnerability of the surface water to pollution is a reality in the lower Ouémé valley in south-eastern Benin. Yèhouénou (2005) has mumbled in his work that fishermen use pesticides and aqueous plant extracts on surface waters to capture aquatic species in the lower Ouémé valley. Adjagodo et al (2017), pointed out that the waters of the Ouémé river also constitute the place of comfort for the population who do not have access to a modern defecation system. This research undertaken in the lower Ouémé valley aims to study the overall quality of surface water and the identification of the factors causing its pollution.

Materials And Methods:-

Search area:

The lower valley of the Ouémé is located between latitude 6°24' and 6°52' North and longitude 2°24' and 2°38' East. It is a sub-basin of the Ouémé valley which includes four communes: Adjohoun, Aguégués, Bonou and Dangbo (figure 1). It is characterised by a sub-equatorial climate with the alternation of two rainy seasons and two dry seasons. The hydrographic network is made up of the Ouémé River (510 km) and its tributaries, namely the Djougoudou, Gbadohouin, Wovimè, Hlan, Tovè, Saharo, Sô, Togbodan, Zoudonou and Togododomè rivers.

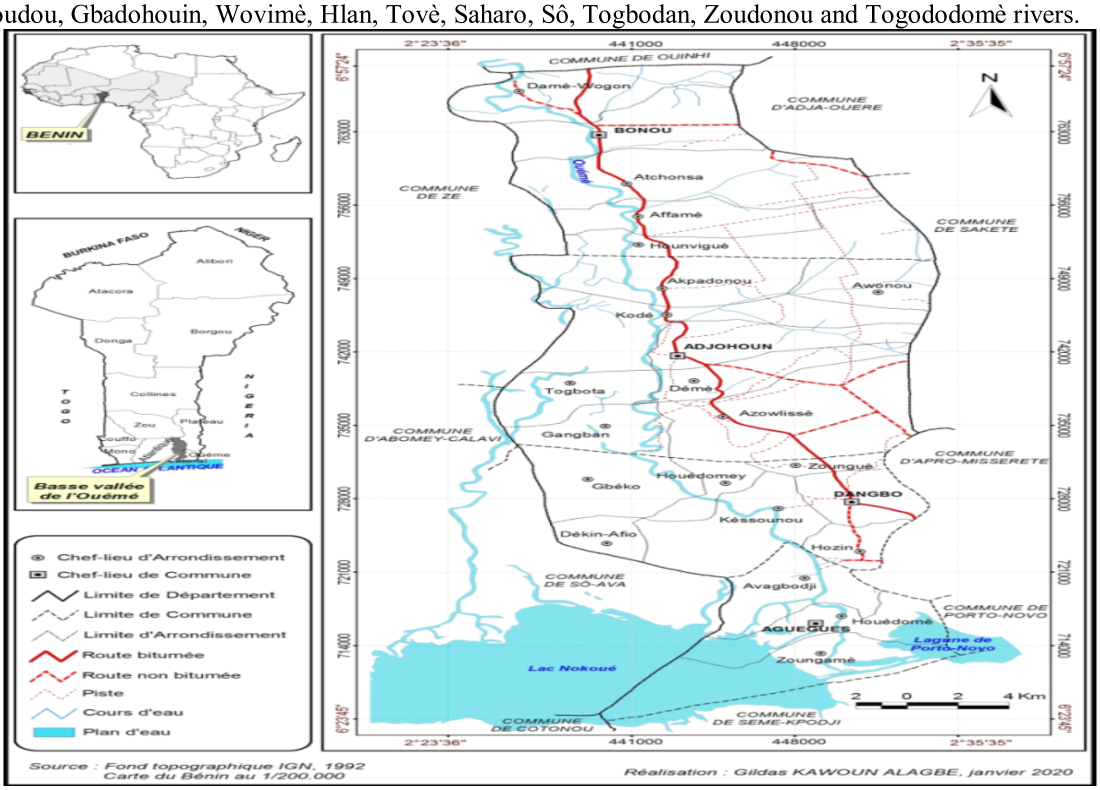


Figure 1:- Geographical location of the lower Ouémé valley.

Data And Materials:-

The water points sampled are selected in places where various activities are carried out, including agriculture, livestock, fisheries, fuel transport and domestic uses near surface waters. A total of seven (07) sampling sites are selected. Eighteen (18) parameters were analysed from each sampling, i.e. one hundredtwenty-six (126) samples per period. Thus, the periods considered are the high waters (August 2018) and the low waters (February 2019). The sampling points are then georeferenced using the GARMIN Global Positioning System (GPS). The photographs were taken using a digital camera. Nalgene high-density polyethylene (HDPE) vials, 60 ml syringes, 47 mm diameter filter holder and 0.45 µm porosity filters were used for the samples. To do this, water was sampled using a clean sump, upstream of potential sources of pollution in order to avoid contamination and directly in watercourses where access was possible with a pirogue.

Methods for processing the results:-

The methodological approach applied to the results of analyses and in situ measurements for physical parameters relates to the comparison of the measured parameters with the WHO potability standards (2011) and those at national level via the Maximum Allowable Concentration (MAC). Subsequently, the data were also processed using the Water Quality Assessment System (WQAS-Water) to determine the overall water quality. An analysis of variance was also performed and the significance test of r at the threshold $\alpha=0.05$ between the means obtained was determined by Pearson's test with Minitab software (X, 2011). Principal Component Analysis (PCA) was also performed using the same software.

Table 1:- Method of analysis of physicochemical parameters.

Dosingparameters	**Reagentsused and other indications**	**Analyticalmethods**
Chloride ion (Cl^-)	Mercurythiocyanate and iron solution	Volumetricmethod: Mercurythiocyanate 8113
Magnesium ion ($Mg2^+$)	Alkaline solutions, EDTA solution, EGTA	Colorimetricmethod
Calcium ion ($Ca2^+$)	Alkaline solutions, EDTA solution, EGTA	Colorimetricmethod
phosphates Ion (PO_4^{3-})	PhosVer 3. Phosphate Reagent for 10 mL sample, Cat. 21060-69 Pk/100. Reagents in AccuVac packets or ampoules	Method 8048: PhosVer 3 method (Ascorbicacid)
Sulfate ion (SO_4^{2-})	SulfaVer 4, Sulfate Reagent for 10 mL sample, Cat. 12065-99 Pk/100. Reagents in capsules or ampoules	Method 8051: SulfaVer 4 method
Nitrates ion (NO_3^-)	NitriVer 2, Nitrite Reagent for 10 mL sample, Cat. 21075-69 Pk/100.	Method 8153: Ferrous sulphate method.
Sodium ion (Na^+)	Hydrochloricacid solution with an accuracy of 5 %	Capillaryelectrophoresis Quanta 4000- Waters withspectrophotometer DR 2800
Potassium Ion (K^+)	Hydrochloricacid solution with 5% accuracy	Capillaryelectrophoresis Quanta 4000- Waters by spectrophotometry
Ammonium ion ($NH4^+$)	Hydrochloricacid solution with 5% accuracy	Capillaryelectrophoresis Quanta 4000- Waters by spectrophotometry
Bicarbonate ion (HCO_3^-)	Sulphuricacid solution with 5% accuracy	Capillaryelectrophoresis Quanta 4000- Waters by spectrophotometry
ChemicalOxygenDemand (COD)	$K_2Cr_2O_7$	Potassium dichromate method
BiochemicalOxygenDemand	Potassium hydroxide KOH	Respirometricmethod OxiTop

Results:-

Physical-chemical characteristics of the waters:

Physico-chemical indicators of water quality are often subject to spatial and temporal variations induced by anthropogenic activities that modify the characteristics of the water and affect its quality (Karrouch et al., 2009).

Physical parameters

Physical parameters include temperature, pH, conductivity, dissolved oxygen, suspended solids and turbidity (Figure 2)

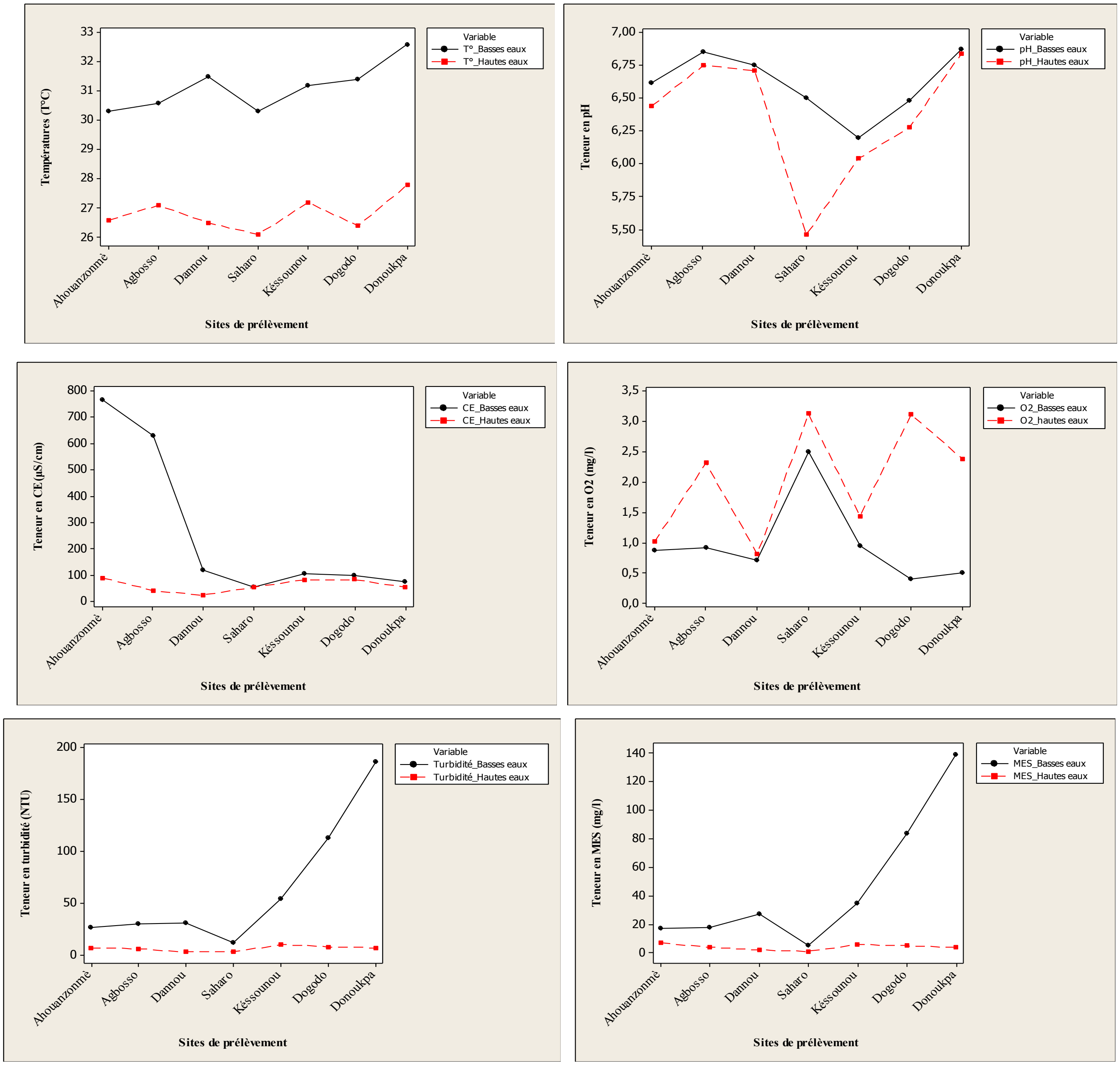


Figure 2:- Spatial and temporal variation of the physical parameters of the sampled waters

Temperatures show a high content during both periods (high waters and low waters), resulting in an excess according to Benin's CMA drinking standard and those of the WHO international standards (2011) which foresee a maximum value of 25 °C due to the influence of solar rays.

As far as pH values are concerned, they oscillate between 6.2 (Dannou) and 6.87 (Ahouanzonmè) in the low water period, and between 5.46 (Saharo) and 6.84 (Ahouanzonmè) in the high water period (HE). This indicates that the waters are acidic with averages varying between 5.46 and 6.87 over the two sampling periods due to the strong mineralization and the presence of organic matter in the waters.

The electrical conductivity values measured on all the sampled waters are relatively low and below the CMA standard for water potability (2000 µS/Cm) and the WHO standard (1500 to 2000 µS/Cm) during both periods. They vary between 24.8 µS/Cm (Késsounou) and 90.1 µS/Cm (Dogodo) downstream in the high water period. As regards the low water period, the values oscillate between 54.7 µS/Cm (Saharo) and 768µS/Cm (Dogodo) downstream depending on the direction of water flow.

For dissolved oxygen, in the high water period the values vary between 5.3 mg/l and 8.5 mg/l with a mean of 6.246 mg/l and a standard deviation of 1.992 mg/l. The maximum value is obtained at the level of the Ouémé river in Ahouanzonmè and the minimum value is recorded in Dogodo. However, during low water periods, oxygen levels are of the order of 4.3 mg/l and 8.1 mg/l with a mean of 5.3 mg/l and a standard deviation of 2.383 mg/l.

As far as turbidity is concerned, the values during both periods vary between 3 mg/l and 186 mg/l with averages of around 6.286 mg/l and 64.7 mg/l. The high value (186 mg/l) is recorded at Ahouanzonmè during the low waters and the lowest at Saharo and Késsounou with 3 mg/l. Thus, the increase in turbidity reflects the presence of particles suspended in the water (organic debris, clays, etc.). As for the contents of suspended matter, during both periods, they vary between 1 mg/l (high waters) and 139 mg/l (low waters) with averages around 4.143 mg/l and 46.4 mg/l. The high value of suspended matter (139 mg/l) is recorded at Ahouanzonmè during low waters due to the accentuation of water erosion in this place, which carries particles from the banks. On the other hand, the lowest level (1 mg/l) is recorded at the Saharo stream due to the clear appearance of the water and its low turbidity. Chemical parameters

Temporal evolution of major cations

The cations involved are Ca2+, Mg2+, Na+ and K+. Thus, their temporal evolution is shown in the figure 3.

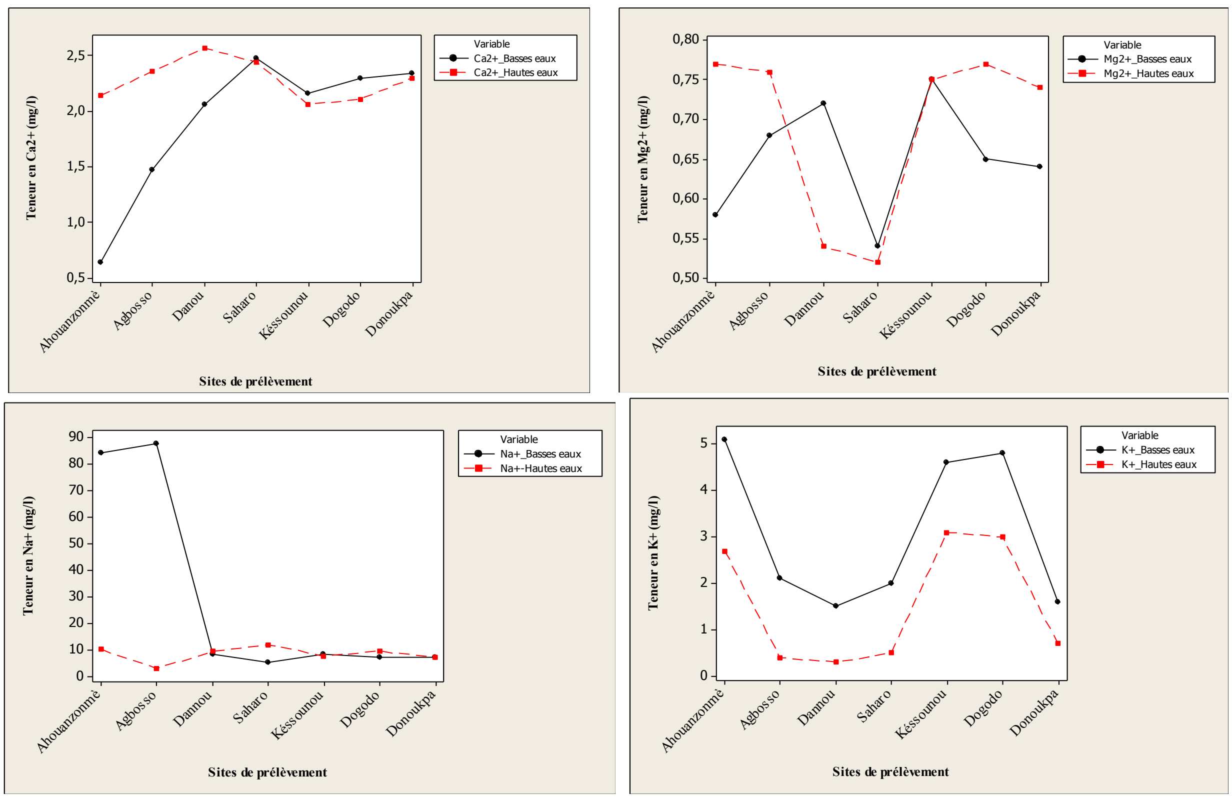


Figure 3:- Spatial and temporal variation of the major cations in the sampled waters.

Calcium levels during both periods vary between 0.64 mg/l (low waters) and 2.57 mg/l (high waters) with averages that vary between 2.2829 mg/l and 1.921 mg/l. The high calcium content (2.57 mg/l) is recorded at Késsounou in high waters and the lowest (0.64 mg/l) at Dogodo.

As far as magnesium contents are concerned, the values are low. During both periods the values oscillate between 0.52 mg/l and 0.77 mg/l during the high water period with averages of around 0.6929 mg/l and 0.6514 mg/l. However, the high magnesium content (0.77 mg/l) is obtained in Dogodo and the lowest (0.52 mg/l) in Saharo in high waters.

As far as sodium contents are concerned, the values obtained during both periods range from 3.24 mg/l (high waters) to 87.8 mg/l (low waters) with averages of 8.63 mg/l and 29.9 mg/l. The highest level (87.8 mg/l) is recorded in Donukpa (low waters) and the lowest (3.24 mg/l) in the same sampling site (high waters).

As for potassium, the values obtained during both periods show low concentrations, ranging from 0.3 mg/l (high waters) to 5.1 mg/l (low waters), with averages around 1.529 mg/l and 3.1 mg/l. The high concentration (5.1 mg/l) is recorded in Dogodo in low waters due to the usual watering of cattle in this place and the lowest (0.3 mg/l) in Késsounou (high waters). It therefore appears that all the waters sampled have concentrations below the MCA and WHO (2011) drinking water standards during both periods.

Temporal evolution of major anions

The anions studied in the framework of this research are Cl-, SO42- and HCO3- which show a varied temporal evolution (figure 4).

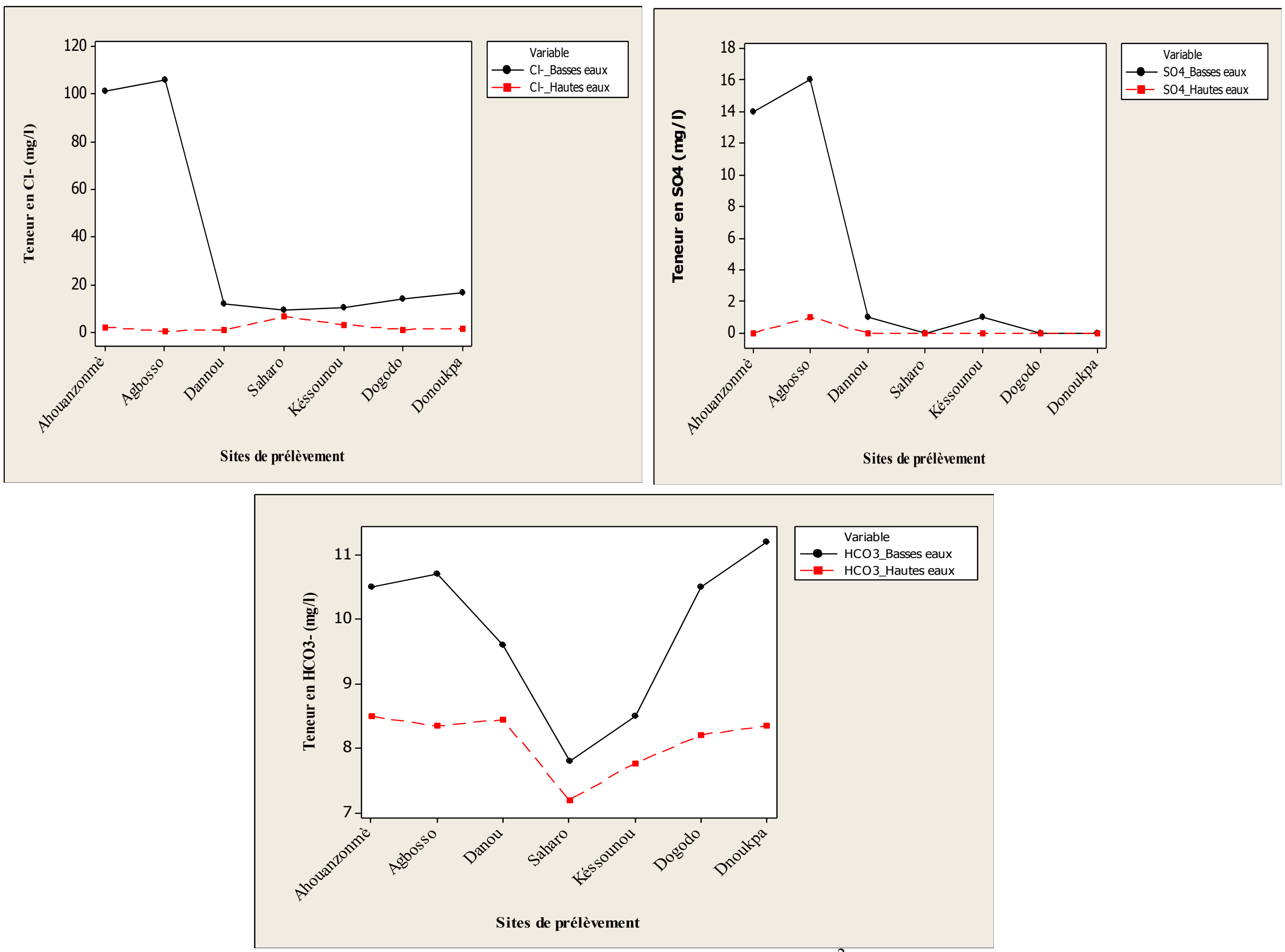


Figure 4:- Spatial and temporal variation ofCl^-, SO_4^{2-}et HCO_3^-

Chloride levels during the two periods vary between 0.5 mg/l (high waters) and 105.7 mg/l (low waters) with averages between 2.314 mg/l and 38.5 mg/l. The highest chloride content (105.7 mg/l) is obtained in Donukpa (low waters) and the lowest (0.5 mg/l) in the same sampling site. However, a value (101.2 mg/l) is observed in Dogodo which tends to be at its highest downstream from the Ouémé River. Chloride levels are well below the MAC standards for water potability and the WHO (2011).

Sulphate levels during the two periods vary between 0 mg/l (high waters) and 16 mg/l (low waters), completely below the MAC and WHO (2011) drinking water standards. However, there are certain sulphate levels in low waters in Dogodo (14 mg/l) and Donoukpa (16 mg/l) which are linked to the leaching of agricultural land, the use of chemical fertilisers and the use of washing powder by local residents.

As for bicarbonate ions, the levels recorded during the two periods vary between 7.2 mg/l (high waters) and 11.2 mg/l (low waters) with averages between 8.119 mg/l and 9.83 mg/l. The high bicarbonate content (11.2 mg/l) is obtained in Ahouanzonmè (low waters) and the lowest (7.2 mg/l) in Saharo.

Nutrients and organic matter

The nutrients studied are phosphates (PO43-), nitrates (NO3-) and ammonium (NH4+) and the organic matter concerns the chemical oxygen demand (COD) and biochemical oxygen demand (BOD5). Their spatio-temporal evolution is shown in Figure 5.

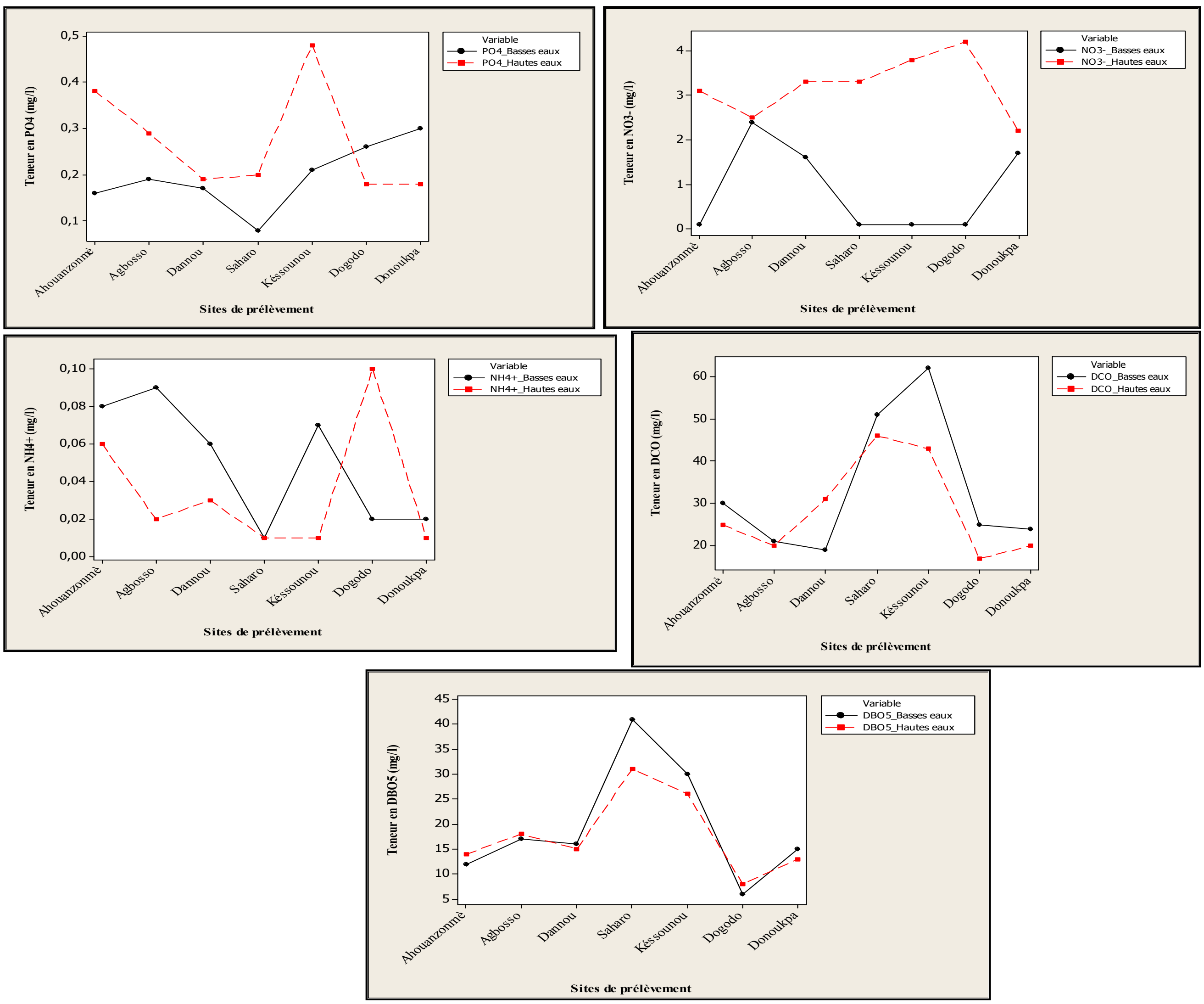


Figure 5:- Spatial and temporal variation of nutrients and organic matter

Ammonium (NH4+) contents vary between 0.01 mg/l during both periods and 0.1 mg/l (high waters) with averages between 0.0343 mg/l and 0.05 mg/l. The high ammonium content (0.1 mg/l) is obtained at Agbosso during high waters due to the regular transport of petroleum products on this site and the lowest (0.01 mg/l) recorded at Ahouanzonmè and Saharo. Thus, ammonium levels at all the sampling sites are below the MAC standards for water potability (5 mg/l) and WHO (2011) standards (≤ 0.5).

Nitrate contents vary between 0, 1 mg/l (low waters) and 4.2 mg/l (high waters) with averages varying between 0.871 mg/l and 3.2 mg/l. The high nitrate content (4.2 mg/l) is obtained in Agbosso (high waters) and the lowest (0.1 mg/l) recorded at four (04) sampling sites, namely Agbosso, Dannou, Saharo and Dogodo in low waters. Thus, these nitrate levels are well below the MAC standards for water potability (45 mg/l) and the WHO (2011) (≤ 50). Phosphate contents vary between 0.08 mg/l (low waters) and 0.48 mg/l (high waters) with averages varying between 0.1957 mg/l and 0.2714 mg/l. The high phosphate content (0.48 mg/l) is obtained in Dannou (high waters) and the lowest (0.08 mg/l) recorded in Dogodo in low waters. However, the phosphate contents of the sampled waters are low and below the MAC standards for water potability (5 mg/l) but very close to the limit value of the WHO standards (2011) (≤ 0.5).

As far as BOD5 is concerned, the BOD5 contents oscillate between 6 mg/l (low waters) and 41 mg/l during the same period with averages varying between 17.86 mg/l and 19.57 mg/l. The high BOD5 content (41 mg/l) is obtained at Saharo and the lowest (6 mg/l) recorded at Agbosso (low waters). Thus, BOD5 levels are well above the WHO (2011) standards (≤ 6 mg/l). As for COD, the levels vary between 17 mg/l (high waters) and 62 mg/l (low waters) with averages of around 28.86 mg/l and 33.14 mg/l. The highest level (62 mg/l) is recorded in Dannou and the lowest (17 mg/l) in Agbosso. With regard to the values obtained, the COD contents are above the WHO standards (2011) (≤ 10 mg/l).

Statistical processing of the data:

According to the criterion of (Kaiser, 1960), two factors were taken into account in explaining the information (Table 2) during the two hydrological periods. In the high-water period, factor 1 is the most important, with an expressed variance of 40.1%, and factor 2 is 29% of the expressed variance. On the other hand, in the low-water period, the factorial axis F1 is represented by 37.3%, and F2 is 33.4%. These two factors favour the significant representation of point clouds and contain the maximum amount of information sought.

Table 2:- Factorsretained for PCA in high and low waters.

	High water		**Low water**	
Factor axes	F1	F2	F1	F2
Own values	7,2426	5,2211	6,7054	6,0032
Variance (%)	40,1	29	37,3	33,4
Cumulative variance (%)	40,1	69,1	37,3	70,7

Variable-factor linkage

The relationship between the variables taken in pairs during periods of high water and the correlation coefficients are given by the correlation matrix (Table 3). Thus, the pH shows a significant binding (0.827 to 0.831) with Turbidity and Mg2+. T°C is also bound (0.92 to 0.93) with Cl- and HCO3-. CE is bound (0.922 to 0.934) with K+ and Ca2+. Turbidity is significantly correlated (-0.93 to 0.862) with Ca2+, K+, MES and Mg2+. 0.619) and MES (0.933). TSS is correlated (-0.87 to 0.878) with Ca2+, K+ and Mg2+. HCO3- bicarbonates are negatively correlated (-0.854 to -0.809) with BOD5 and COD. Cl- is correlated (0.822 to 0.832) with BOD5 and COD and SO42- is significantly (0.833) related with Na+ as well as COD which is highly correlated at 0.911 with BOD5.

During low water periods, the existing relationship between the variables and the correlation coefficients between the variables is indicated through the correlation matrix (Table 4). Thus, pH shows a linkage (0.771 to 0.849) with TSS, Turbidity and PO43. T°C is correlated (-0.841 to 0.827) with COD and NO3-. CE is both negatively and positively correlated (-0.96 to 0.986) with Ca2+, SO42-, Cl- and Na+. O2 is bound (-0.838 to 0.882) with PO43-, HCO3- and BOD5. Turbidity is positively correlated (0.896 to 0.998) with MES and PO43-. Ca2+ is negatively correlated (-0.9 to -0.88) with Na+, SO42- and Cl-. NH4+ is positively (0.777) correlated (0.777) with SO42-. Cl- is positively bound (0.994 to 0.998) with SO42- and Na+. SO42- is positively (0.998) bound with Na+ and COD is positively (0.998) correlated with BOD_5.

Table 3:- Correlation of parameters at the 5% threshold during high water periods

	pH	T°	CE	O2	Turb	MES	HCO_3^-	Ca^{2+}	Mg^{2+}	K^+	NH_4^+	NO_3^-	PO_4^{3-}	Cl^-	SO_4^{2-}	Na^+	DCO	DBO5
pH	1																	
T°	0,474	1																
CE	0,431	-0,34	1															
O2	0,108	-0,4	0,096	1														
Turb	**0,827**	0,1	0,741	-0,032	1													
MES	0,642	0,25	0,781	-0,328	**0,852**	1												
HCO_3^-	0,453	**0,93**	-0,099	-0,5	0,16	0,439	1											
Ca^{2+}	-0,674	0,13	**-0,934**	-0,058	**-0,93**	**-0,87**	-0,037	1										
Mg^{2+}	**0,831**	0,4	0,622	0,007	**0,862**	**0,878**	0,477	-0,807	1									
K^+	0,517	-0,22	**0,922**	-0,098	**0,802**	**0,813**	0,032	-0,926	0,612	1								
NH_4^+	0,343	0,08	0,497	0,133	0,232	0,406	0,376	-0,42	0,368	0,572	1							
NO_3^-	0,05	-0,54	0,481	0,07	0,253	0,159	-0,31	-0,407	-0,05	0,67	0,565	1						
PO_4^{3-}	0,128	-0,15	0,526	-0,498	0,619	0,684	-0,053	-0,604	0,44	0,583	-0,18	0,175	1					
Cl^-	-0,622	**-0,92**	0,146	0,311	-0,3	-0,4	-0,915	0,095	-0,56	-0,05	-0,35	0,209	0,06	1				
SO_4^{2-}	0,005	0,35	-0,355	0,132	-0,05	-0,03	0,216	0,18	0,265	-0,38	-0,19	-0,45	0,069	-0,395	1			
Na^+	-0,446	-0,64	0,276	0,038	-0,31	-0,21	-0,436	0,036	-0,53	0,211	0,251	0,501	-0,18	0,659	**-0,833**	1		
DCO	-0,612	-0,77	-0,02	-0,101	-0,21	-0,35	**-0,809**	0,146	-0,6	-0,03	-0,55	0,29	0,347	**0,832**	-0,336	0,469	1	
DBO_5	-0,61	-0,74	-0,093	0,102	-0,22	-0,38	**-0,854**	0,178	-0,49	-0,2	-0,7	0,036	0,339	**0,822**	0,008	0,198	**0,911**	1

In bold, significant values (excluding diagonal) at threshold alpha=0.05 (bilateral test)

Table 4:- Correlation of parameters at the 5% threshold during low water periods

	pH	T°	CE	O2	Turb	MES	HCO_3^-	Ca^{2+}	Mg^{2+}	K^+	NH_4^+	NO_3^-	PO_4^{3-}	Cl^-	SO_4^{2-}	Na^+	DCO	DBO_5
pH	1																	
T°	0,138	1																
CE	-0,254	0,309	1															
O2	-0,553	-0,256	-0,131	1														
Turb	**0,79**	0,245	-0,396	-0,568	1													
MES	**0,771**	0,27	-0,41	-0,585	**0,998**	1												
HCO_3^-	0,438	0,677	0,422	**-0,784**	0,575	0,583	1											
Ca^{2+}	0,297	-0,216	**-0,96**	0,201	0,392	0,398	-0,387	1										
Mg^{2+}	0,496	-0,143	-0,19	-0,571	0,099	0,109	0,071	0,152	1									
K^+	-0,112	-0,659	0,294	-0,247	-0,07	-0,1	0,014	-0,4	0,005	1								
NH_4^+	-0,043	0,077	0,75	-0,276	-0,49	-0,5	0,185	-0,76	0,448	0,224	1							
NO_3^-	0,386	**0,827**	0,179	-0,311	0,17	0,187	0,513	-0,04	0,34	-0,73	0,303	1						
PO_4^{3-}	**0,849**	0,199	-0,191	**-0,838**	**0,896**	**0,894**	0,705	0,185	0,43	0,11	-0,122	0,27	1					
Cl^-	-0,176	0,398	**0,983**	-0,12	-0,34	-0,36	0,468	**-0,89**	-0,19	0,186	0,721	0,302	-0,147	1				
SO_4^{2-}	-0,195	0,362	**0,976**	-0,091	-0,42	-0,43	0,402	**-0,88**	-0,12	0,169	**0,777**	0,319	-0,197	**0,994**	1			
Na^+	-0,203	0,363	**0,986**	-0,1	-0,39	-0,41	0,426	**-0,9**	-0,16	0,199	0,75	0,284	-0,184	**0,998**	**0,998**	1		
DCO	-0,04	**-0,841**	-0,307	0,574	-0,28	-0,32	-0,814	0,269	-0,02	0,318	-0,104	-0,64	-0,363	-0,36	-0,31	-0,323	1	
DB	-	-	-	**0,8**	-	-	**-**	0,3	-	-	-	-	-	-	-	-	**0,7**	1

O_5	0,216	0,425	0,339	**82**	0,44	0,46	**0,884**	82	0,2	0,27	0,202	0,26	0,648	0,33	0,27	0,3	**93**	
In bold, significant values (excluding diagonal) at threshold alpha=0.05 (bilateral test)																		

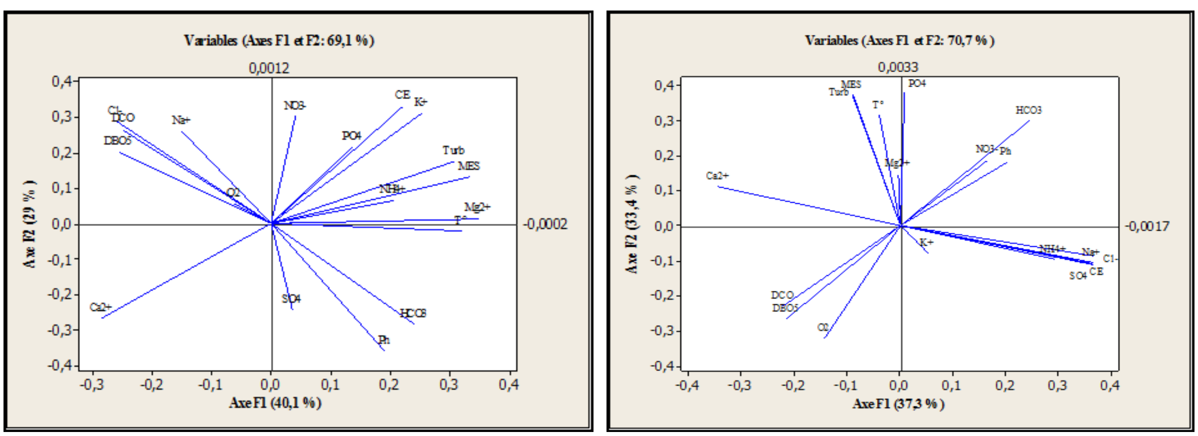
Spatial analysis of physico-chemical parameters

The projection of the variables in the factorial planes (F1-F2) during the two periods is shown in Figures 6a and 6b. Analysis of Figure 6a indicates that the factorial (F1-F2) plane during the high water period accounts for 69.1% of the total variance. The significant factor 1 (40.1%) is determined in its positive part by PO4 3-, EC, K+, turbidity, NH4+, TSS, T°C and Mg2+ and in the negative part by Ca2+. The presence of T°C and PO43- results in the environmental and man-made conditions due to the use of phosphate fertilizers in agriculture. The factor 2 is determined in its positive part by BOD5, COD, Cl-, O2 and NO3- and in its negative part by pH, HCO3- and SO42-. These variables are of anthropogenic origin, probably resulting from domestic wastewater discharges.

In low water periods, figure 6 b shows the factorial design (F1-F2) which represents 70.7 % of the total variance. The significant factor 1 (37.3 %) is determined in its positive part by NH4+, Na+, Cl-, EC, SO42-. In its negative part by HCO3-, NO3-, pH and Ca2+. As for the F2 axis, it is correlated in the positive part by TSS, turbidity, T°C, Mg2+ and in the negative part by Ca2+ and PO43- and negatively by COD, BOD5 and O2.

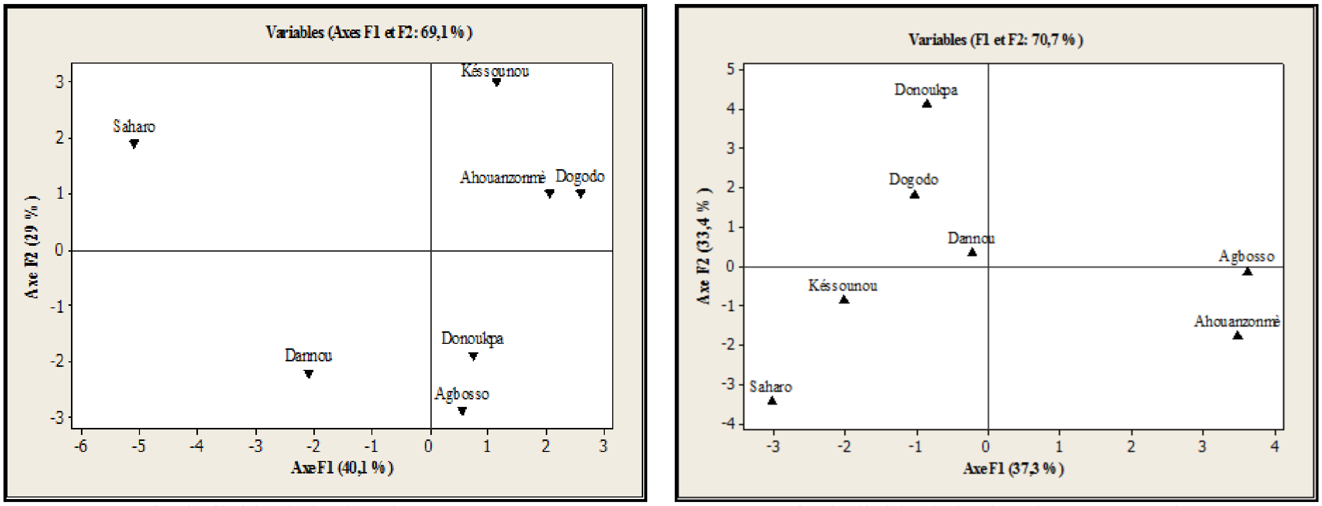
Analysis of the space of individuals

The projection of the high water sampling sites in the factorial plane F1-F2 is shown in Figure 7a. It can be seen that the surface waters of the lower Ouémé valley show 4 groupings. The first takes into account the de Késsounou, Ahouanzonmè and Dogodo groups, characterised by waters with little oxygen. The second concerns Donoukpa and Agbosso, the third Dannou of fair quality and the fourth Saharo of very good quality. In periods of low water, three groupings are observed. The first takes into account Donoukpa, Dogodo and Dannou, the second groups Agbosso and Ahouanzonmè upstream represented by good quality water and the third concerns Késsounou with very poor quality water and Saharo with very good quality water.



Plane variable space (F1-F2) (a) Plane variable space (F1-F2) (b)

Figure 6:- Projection in the factorial planes (F1-F2) of the surface waters of the lower Ouémé valley



Space for individuals in the plan (F1-F2) (a) Space for individuals in the plan (F1-F2) (b)

Figure 7:- Projection of individuals in the factorial planes (F1-F2) of the waters of the lower Ouémé valley

Table 5:- Grid for classifying overall water quality according to SEQ-Water of physico-chemical parameters

Variables	**High water period**	**Water quality classes**					**Low water period**	**Water quality classes**				
	Moy	**I**	**II**	**III**	**IV**	**V**	**Moy**	**I**	**II**	**III**	**IV**	**V**
pH	6,36						6,61					
T (°C)	26,814						31,129					
CE (µS/cm)	61,87						265					
O_2 (mg O_2/l)	6,246						5,3					
Turbidité	6,286						64,7					
MES (mg/l)	4,143						46,4					
Ca^{2+} (mg/l)	2,2829						1,921					
Mg^{2+} (mg/l)	0,6929						0,6514					
K^+ (mg/l)	1,529						3,1					
NH_4^+ (mg/l)	0,0343						0,05					
NO_3^- (mg/l)	3,2						0,871					
PO_4^{3-} (mg/l)	0,2714						0,1957					
Cl^- (mg/l)	2,314						38,5					
SO_4^{2-} (mg/l)	0,143						4,57					
Na^+ (mg/l)	8,63						29,9					
DCO (mg/l)	28,86						33,14					
DBO_5 (mg/l)	17,86						19,57					

Very good	**Good**	**Passable**	**Wrong**	**Verywrong**

The results show that during both periods, the surface waters are of "very good quality" 47.06% and 52.94%, of "good quality" 41.18% and 11.76%, of "fair quality" 17.65% observed only in low waters, of "poor quality" 5.88% and 11.76% and finally of "very poor quality" with 5.88%.

Discussion:-

The results of the analyses indicate that the highest levels of the electrical conductivity of the water are obtained in the localities of Dogodo and Donoukpa during the low water period due to their proximity to Lake Nokoué which is subject to marine intrusion during this period depending on the natural conditions. Iounes et al (2016), the degradation of the physico-chemical quality of the Daliyawadi in Morocco is probably linked to the change in natural conditions which are closely linked to the installation of the dry season but also to the proliferation of algae in the river bed. Similarly, the high levels (COD and BOD5) well above WHO standards (2011) increase the pollution load of organic matter in surface waters. This confirms the work of AguizarAbai et al (2014) who referred to the high organic matter content that can disturb the development of aquatic life in the watercourses of Ngaoundéré, Cameroon. Spatial and temporal monitoring of several physico-chemical parameters of the water of the OuedSeybouse in Algeria reveals a relatively intense pollution which is reflected in a significant mineral and organic load downstream of the Oued in Algeria (Reggam et al., 2015). The surface water of the lower valley also presents a quasi-persistent presence of PO_4^{3-}, NO_3^-, NH_4^+ and BOD_5 ions. This is in line with the work of Attingli et al. (2017) who have shown that these parameters do not depend on the hydrological cycle but on the fishing zones. According to Djèdjiho (2014), the waters of the Lake Ahémé-Gbézounmè lagoon complex in Benin have very high mineral contents such as nitrite, nitrate and phosphate ions as well as COD and BOD5 concentrations in the water samples analysed. At the level of the Kadicha River in northern Lebanon, the anthropogenic activities carried out (direct discharges of domestic wastewater, leachates and oil mill effluents) pollute surface water (Merhabi et al., 2019). These observations, which relate to the lack of sanitation and hygiene practices, are similar to the sources of surface water pollution in the lower Ouémé valley. As for the overall water quality according to SEQ-Eau, it shows an overall 47.06% very good quality and 5.88% poor and very poor quality. This is not similar to the results obtained by Tohouri et al (2017) who showed that 92.86% of the surface water in the Bonoua region of Côte d'Ivoire is of average overall quality and only 7.14% is of poor overall quality.

Conclusion:-

The global water quality indicates that the TSS and BOD5 parameters in low waters and the temperature in high waters show a poor state. However, very poor water quality is recorded in terms of temperature in low water periods and BOD5 in high water periods. The same is true for the links between the parameters studied during the high water period, both positive and negative correlations are observed between the physico-chemical parameters. For significant correlations between the parameters studied during the low water period, strong positive correlations exist between the physico-chemical variables (NH4+, Na+, Cl-, EC and SO42-) during the low water period due to the discharge of wastewater. However, in high waters, a positive correlation has been observed between Mg2+ and T°C due to the environmental conditions.

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