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Spatial and Seasonal Characterization of the Physico-Chemical Quality of the Water of the Tovè River in the Southern Benin (West Africa)

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ABSTRACT

A characterization of the water of the Tovè River has been achieved in order to have basic data for subsequent investigations on the ichthyofauna's state of this river and to develop appropriate measures to avoid the loss of its aquatic biodiversity. Thus, the spatio-temporal variations of dissolved oxygen, pH, temperature, conductivity, salinity, water transparency, depth, velocity, total dissolved solids (TDS), nitrite (NO_2^-), nitrate (NO_3^-), phosphate (PO_4^{3-}), magnesium (Mg^{2+}), calcium (Ca^{2+}), sulfates (SO_4^{2-}) and ammonium (NH_4^+) were surveyed from October 2015 to September 2016. The correlation analysis of the collected data showed strong correlations between these water parameters. The Kruskal-Wallis test showed that the variation of the physico-chemical parameters of the River was strongly influenced by hydrological seasons ($p < 0.001$). Excepted the calcium, magnesium and temperature values, all the surveyed parameters of the Tovè River waters presented relative high values during the rainy and flood seasons which were mostly beyond the MDDEFP guideline values relative to the protective criteria of the aquatic life (chronic effect), due to runoff drainage, which includes all chemicals generated by anthropogenic activities (manure waste, biomedical waste, leaching, domestic wastewater discharges) along the bank.

Key words: *Tovè River, Rainy Season, Dry Season, Physico-Chemical Parameters, Benin.*

INTRODUCTION

West Africa, through the variety of its water reservoirs, contains an unique biodiversity and is considered as one of the priority areas for global conservation. However, this biological heritage, which is still poorly known, is subject of unsustainable exploitation and is threatened with an imminent disappearance[1]. The biological diversity of fish in the whole West African sub-region is threatened by the increased pressure exerted by riparian populations on wetland habitats and resources and by changes in the environment[1].

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The problem of water resources therefore arises acutely because of their irregularity in time and space. This irregularity of water resources induces crises linked either to its lack or to its excess. This water problem is aggravated by the almost uniform decline in precipitations over the last fifty years, the seasonal irregularities, the rapid spread of desertification and the gradual deterioration of environmental factors[2].

Awareness of this ecological drift therefore depends on the need to take conservation measures. These measures to be effective require a prior knowledge of fluctuation of physico-chemical parameters (temperature, dissolved oxygen, pH ...) that influence species distribution in this precious water reservoir[3 – 5]. Each of these factors directly or indirectly plays a key role on ichthyfauna's life and ecology. The temperature of the water plays an important role, for example with regard to the solubility of salts and gases such as the oxygen which is necessary to the balance of the aquatic life. The importance of velocity, stream size and substrate in determining the composition of fish communities was indicated by Gorman *et al.*[6] and Hugueny [7].

According to Aboua[8], dissolved oxygen is probably the most important parameter in natural surface water systems to determine the health of aquatic ecosystems. The concentrations in NO_2^-, NO_3, NH_3 and NH_4^+, PO_3^-, N and P are among the important parameters of the quality of the surface waters to survey[9]. Physico-chemical measurements, in addition to their interest in water use standards, appear essential for decontamination actions and for applying regulations on discharges[10].

Water, which is an indispensable part of life and for countless human activities such as agricultural and agro-industrial activities must be preserved.

In view of all these interests required by water reservoirs, a more complete diagnosis of the current situation of their contamination and a rigorous follow-up of their evolution through the measurement of physicochemical parameters are essential for the preservation of these resources. In fact Tovè River, is an affluent of the Ouémé River, the largest river in the region,—but no information is available on physico-chemical fluctuation of this reservoir.

The present investigation aims to access (i) the spatio-seasonal fluctuation of water quality in the Tovè River and (ii) the water quality of the river in relation to natural water standards in order to characterize this ecosystem.

MATERIALS AND METHODS

Study area

The Tovè River is located in the Southern Benin (04°42'47" N, 07°45'2" W). Benin country is located in West Africa at 6° 15' and 12° 25' North latitude and 0 ° 45' and 04 °00' East longitude. It is bounded at the North by Niger and Burkina Faso, at the East by Nigeria, at the West by Togo and South by the Atlantic Ocean. Its surface area is estimated at 114 763 km^2 (along 700 Km about 125 km wide and 325 km South to North).

With an approximately length of 1 km, with an average width of 3 m, the Tovè River is located in the Ouémé Division, specifically in the Adjohoun Sub Division at about 32 Km from Porto-Novo (Administrative Capital of Benin). The Sub-Division is limited at the South by the Dangbo Sub Division, at the North by the Bonou Sub-Division, at the East by the Sakété Sub-Division and at the West by the Abomey-Calavi and Zè Sub-Divisions. This river rises in the swamp of Tovè at Tovègbamè and flows into the Ouémé River, the largest river of Benin.

In order to have exhaustive ichtyofauna inventory of this ecosystem, and its spatial distribution in this river, the river was divided into three main areas A, B and C respectively upstream, middle stream and downstream of the river (Fig. 1).

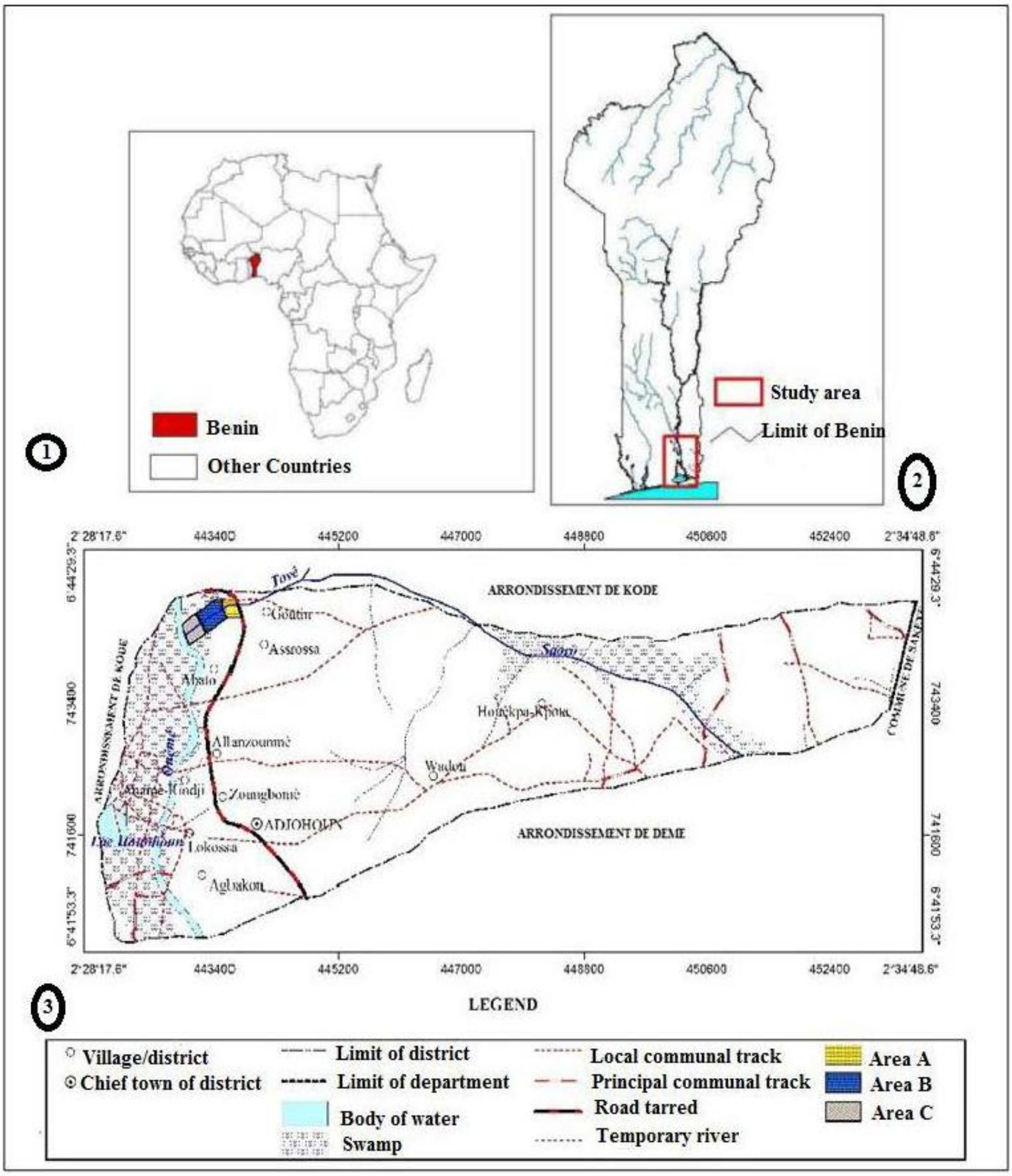

Fig. 1: Study Area of Tovè River (3) located in Southern of Benin (2), Country situated in West Africa (1)

Study of physico-chemical parameters

Sampling

In situ measurement and water sampling campaigns were assessed seasonally during each of the four hydrological seasons occurred the study area, corresponding to four sampling campaigns. The sampling schedule followed is summarized in Table 1. Due to the diversity of habitats in this river, it was subdivided into three sectors (the upstream, sector A, where the river takes its source, the middle stream, sector B, the downstream, sector C, where the river flows into the Ouémé River) as shown in fig 1. Three sampling sites are selected in each sector for data collection. At each sampling site, 0.5 L of water was sampled from the surface in a hermetically sealed plastic bottle. The water samples were then transported in an icebox at low temperature (T ° ≤ 4 °C) in the laboratory for analysis. The physico-chemical *in situ* parameters of the water were measured between 6 AM and 11 AM at all sampling sites.

Table 1: Calendar of samplings

Periods	Seasons	Sampling periods
September – November	Flood (Minor rainy season)	27-28-29 October 2015
November – April	Subsidence (Major dry season)	28-29-30 January 2016
April – June	Flood (Major rainy season)	26-27-28 May 2016
June – September	Subsidence (Minor dry season)	08-09-10 September 2016

Physico-chemical analyses

Portable digital multi-parameter Odéon type version 5.1 display was used for *in situ* measurements of: Dissolved Oxygen, Temperature, Conductivity, Salinity and Total Dissolved Solids (TDS). The apparatus of ORCHIDIS Laboratory of the group AQUALABO permitted to measure the main chemical salts, namely : Nitrite ($NO2^-$), nitrate (NO_3^-) phosphate (PO_4^{3-}), magnesium (Mg^{2+}), calcium (Ca^{2+}), sulfates (SO_4^{2-}) and ammonium (NH_4^+) of the waters of the Tovè River. The values of the salts were obtained in the laboratory by means of reagents in the form of pellets in tablets intended for the determination of the dissolved salts concerned. The principle of measure is based on the Beer Lambert law which indicates the proportionality of the optical density with the thickness of the solution (sample analyzed) and the concentration of the desired chemical element. After addition of the appropriate reagent, the water-reagent sample mixture is introduced into the spectrometer which displays the concentration of the ion as compared with a control solution consisting of a sample of the water to be analyzed without the reagent. The measures of the transparency are carried out by total immersion followed by a gradual rise of a Secchi disk between 10 AM and 3 PM so that the lighting level is constant [11]. The graduated wire then determines the thickness of the euphotic zone in m. The river was not too deep, so that the same disc of Secchi allowed evaluating the average depths. The depth corresponds to the length of the submerged rope. The current velocity was measured by timing the movement of a 0.5 liter plastic bottle half full of water over a given distance [12] of 7 m. The seasonal pH of the waters of the Tovè River was evaluated using a Waterproof pH-meter pH 300/310. Water temperature, salinity, dissolved oxygen, pH, water transparency, depth, TDS and velocity are measured *in situ*.

The values of most of the parameters were compared with the guideline value of the Ministry of the lasting Development of the Environment of Fauna and the Park [13] of the Québec government concerning Surface Water Quality Criteria, section, Criteria for the Protection of Aquatic Life available on its website at http://www.mddefp.gouv.qc.ca/eau/criteres eau. In this document, two chemical quality criteria are established to assure a protection to short and long-term of all aquatic organisms: an acute aquatic life criterion and a chronic aquatic life criterion. In the current study, the second criterion that relates to the highest concentration of a substance was considered so that it will not have any adverse effect on aquatic organisms (and their offspring) when exposed daily throughout their lives.

For the parameters that have not been compared, no quality criterion for the protection of aquatic life has been adopted yet by the MDDEFP.

Statistical Treatments

The correlation matrix was established to show the correlation coefficients between the various parameters measured. The correlation coefficient determines relationship between two variables and measures the intensity of this link. It varies between -1 and +1. When it is equal to 1, it indicates a link between the variables and if it is equal to 0, it indicates an absence of link. The sign + implies that the relation is proportional whereas the sign - means that the relation is inversely proportional.

The Shapiro-Wilk test was applied to verify if the physicochemical parameters of the river follow a normal distribution. The Kruskal-Wallis test was used to test the variability of parameters between seasons and defined sites. Then the abiotic typology was carried out by a principal component analysis on the mean values of the various parameters measured in order to know the parameters that discriminate the three sectors of the studied river. All the statistical analyses were carried out with software R version 2.15.3 with the FactoMineR package.

RESULTS

Spatial and seasonal variations

Table 2 summarizes the results of the physico-chemical analysis of the waters of the Tovè River.

It presents the average values of the various parameters by sector and season and their variations.

Indeed, the Shapiro test carried out on the data of the environmental variables of each water body shows a normal distribution ($p < 0.05$). The Kruskal-Wallis test showed that during a same season none of the sixteen parameters surveyed, showed a significant spatial variation. Reversely, these parameters varied very significantly from one season to another.

Average water temperatures measured on all stations vary between 26.83 ° C and 27.05 °C with an annual average of 26.93 °C (Table 2). The minimum temperature value for all stations was recorded at upstream (25.73 °C) and the maximum value was recorded at the center (29.08 °C). It did not vary significantly from one sector to another. However, it varies very significantly according to the seasons ($p < 0.001$). The lowest average value (25.81 ° C) was recorded during the major rainy season (April - June) and the highest temperature (28.15 ° C) was recorded during the major dry season (November - April) (Fig. 2). The different recorded temperatures fall within in the tolerated range for aquatic species off warm water (25°C to 30°C).

The pH values measured on all sampled sites generally indicate acid values (pH <7). Average values oscillate between 6.39 at upstream and 6.61 at downstream. The mean value for the entire river is 6.48 (Table 2). The maximum pH value (6.94) was obtained during the minor rainy season and the small value (6.08) during the major dry season with a very significant difference between the different seasons of the year (Fig. 2). The guidelines fixed by [13] for the protection of aquatic life are $6.5 < pH < 9$. It could be concluded that the values recorded fall within the limits of the tolerated.

The values of dissolved oxygen have been measured in mg/L. They vary across the river between 1.56 mg/L upstream and 1.80 mg/L downstream. The mean value for the entire river is 1.66 mg/L (Table 2). The lowest values of this parameter were recorded during the dry season, contrary to the highest values recorded during the rainy season (Fig. 2). These different concentrations are lower than the guideline value of MDDEFP which is at least 4 mg/L O_2 for a temperature of 25 °C, indicating that the environment is polluted but reversibly.

The mean conductivity values for all stations range from 62.19 μS/cm downstream to 64.02 μS/cm upstream. They correspond respectively to 31.65 ppm and 32.25 ppm of TDS (Table 2). The conductivity measurement is proportional to that of the TDS. These two parameters experienced very significant variations during the different seasons. The highest and lowest values were recorded during the rainy season and the dry season, respectively (Fig. 2).

The water depth of the Tovè River varies from a sector to another. The higher mean depth value was measured at the center of the river (1.79 m) and the lowest mean value of the river depth was measured downstream (0.98 m).

Table 2: Spatio-temporal variation of the mean values of the parameters measured during the study period

Parameters	Upstream	Middle stream	Downstream	KW	GSP	GSS	PSP	PSS	KW
Trans	1.17 ± 0.54	1.17±0.52	1.17±0.52	**0.80^{NS}**	0.87±0.57	0.87±0.56	0.87±0.38	0.87±0.62	**23.94*** **
Prof	1.13±0.83	1.79±2.14	0.98±2.19	**0.98^{NS}**	2.03±1.04	1.04±0.83	1.53±5.07	1.94±1.26	**28.70*** **
Temp	26.83±0.94	27.05±1.17	26.91±0.88	**0.82^{NS}**	25.81±0.05	28.15±0.41	27.52±0.09	26.24±0.08	**32.71*** **
pH	6.39±0.40	6.46±0.44	6.61±0.48	**1.59^{NS}**	6.68±0.35	6.08±0.14	6.94±0.24	6.24±0.32	**21.76*** **
Sali	0.04±0	0.04±0	0.04±0	**1.95^{NS}**	0.038±0	0.04±0.01	0.04±0	0.04±0	**9.26* **
Cond	64.02±6.60	62.86±6.41	62.19±6.44	**3.27^{NS}**	56.68±1.09	67.82±2.77	70.27±0.72	57.34±0.49	**29*** **
TDS	32.25±3.66	32±3.41	31.65±3.42	**2.85^{NS}**	28.40±0.87	34.93±0.46	35.62±0.48	28.93±0.26	**29.21*** **
O_2	1.56±1.55	1.64±1.54	1.80±1.83	**2.18^{NS}**	4.35±0.49	0.50±0.07	0.91±0.09	0.89±0.08	**29.78*** **
Vite	0.87±0.48	0.65±0.44	0.81±0.51	**1.47^{NS}**	1.41±0.22	0.19±0.11	0.83±0.20	0.66±0.15	**29.97*** **
Mg^{2+}	1.71±0.84	1.70±0.83	1.97±0.93	**0.77^{NS}**	1.25±0.43	2.66±0.38	0.85±0.20	2.41±0.47	**27.84*** **
Ca^{2+}	4.47±2.04	3.99±1.33	5.11±1.79	**3.04^{NS}**	3.10±0.62	6.82±1.53	3.55±0.88	4.62±0.90	**24.10*** **
NH_4^+	1.20±1.04	1.13±0.88	1.16±0.76	**0.04^{NS}**	1.47±0.53	0.42±0.45	2.28±0.30	0.49±0.37	**25.17*** **
NO_2^-	0.43±0.44	0.52±0.56	0.53±0.57	**0.55^{NS}**	0.81±0.13	0.03±0.02	1.09±0.40	0.05±0.01	**27.80*** **
NO_3^-	0.30±0.31	0.32±0.27	0.30±0.29	**0.35^{NS}**	0.60±0.17	0.05±0.06	0.46±0.24	0.09±0.05	**27.51*** **
PO_4^{3-}	0.28±0.22	0.28±0.18	0.27±0.17	**0.04^{NS}**	0.53±0.16	0.12±0.05	0.30±0.09	0.15±0.05	**27.50*** **
SO_4^{3-}	1.27±0.68	1.19±0.58	1.81±0.91	**4.48^{NS}**	1.65±0.81	0.98±0.41	2.18±0.70	0.88±0.15	**17.53*** **
		Spatial Variations				**Seasonal Variations**			

Trans = Transparency, Prof = Depth, Temp = Temperature, Sali = Salinity, Cond = Conductivity, O_2 = Dissolved Oxygen, Vite = velocity, TDS = Total Dissolved Solids, Mg^{2+} = magnesium ion, Ca^{2+} = calcium ion, NH_4^+ = ammonium ion, NO_2^- = nitrite ion, NO_3^- = nitrate ion, PO_4^{3-} = orthophosphate, $SO4^{3-}$ = sulphate ion, KW = Kruskal-wallis, NS= p > 0.05 = not significant, * = p <0.05 = significant, *** = p <0.001 = highly significant, GSP= major rainy season, GSS= major dry season, PSP= minor rainy season and PSS = minor dry season

The depth presented a big variation according to hydrological seasons (p <0.001) over the different sectors. The lowest value (1.04 m) was obtained during the main dry season while the highest (2.03 m) was observed during the major rainy season (Fig. 2).

At the level of transparency, the lowest and highest values were found upstream of the river (Fig. 2), but did not vary significantly from one sector to another. However, the values of this variable showed a highly significant seasonal variation (p <0.001) (Table 2).

On the Tovè River, spatial variations in velocity were not significant. The maximum has been obtained upstream (1.65 cm/s) and the minimum has been recorded in the center (0 cm / s). This same rate experienced a highly significant seasonal variation (p <0.001), with very low values especially during the major dry season (Table 2 and Fig. 2).

From upstream to downstream of the river through the middle stream, there was no large variation in salinity in any season. The value of the latter often oscillated between 0.03 and 0.04 g/L (Fig. 2).

The magnesium ion contents (Mg^{2+}) varied significantly during low and high waters. The minima were obtained during the high waters and the maxima were obtained during the low waters. Spatially, the variations are not significant (Table 2 and Fig. 2).

The concentrations of calcium ion (Ca^{2+}) followed the same evolution as those of magnesium ions during the study. Mean values fluctuated between 2.41 and 3.10 mg/L during high water and between 3.55 and 6.82 mg/L during low water. As magnesium, there is very little variation in calcium from one sector to another (Table 2 and Fig. 2).

The mean spatial values of the ammonium in Tovè waters have been ranged from 1.13 mg/L to 1.20 mg/L, whereas these values varied very significantly with seasons with higher values during high waters (Table 2 and Fig. 2). These values are well above the MDDEFP values which recommend 0.0015 mg / L for protection of aquatic life (chronic effect).

Contrary to magnesium and calcium, mean values of sulphate ions fluctuated between 1.65 and 2.18 mg/L during high water and between 0.88 and 0.98 mg/L during low water. The lowest mean value was obtained downstream of the river (Table 2 and Fig. 2).

The mean value of the highest nitrite level has been measured downstream of the river (0.53 mg/L) and the lowest value (0.43 mg/L) has been measured upstream. The average of nitrites throughout the river is 0.49 mg/L. Almost the same scenario was observed at the nitrate level where the lowest mean value of nitrate has been measured upstream of the river (0.3 mg/L) and the highest value (0.32 mg/L) has been measured at the center.

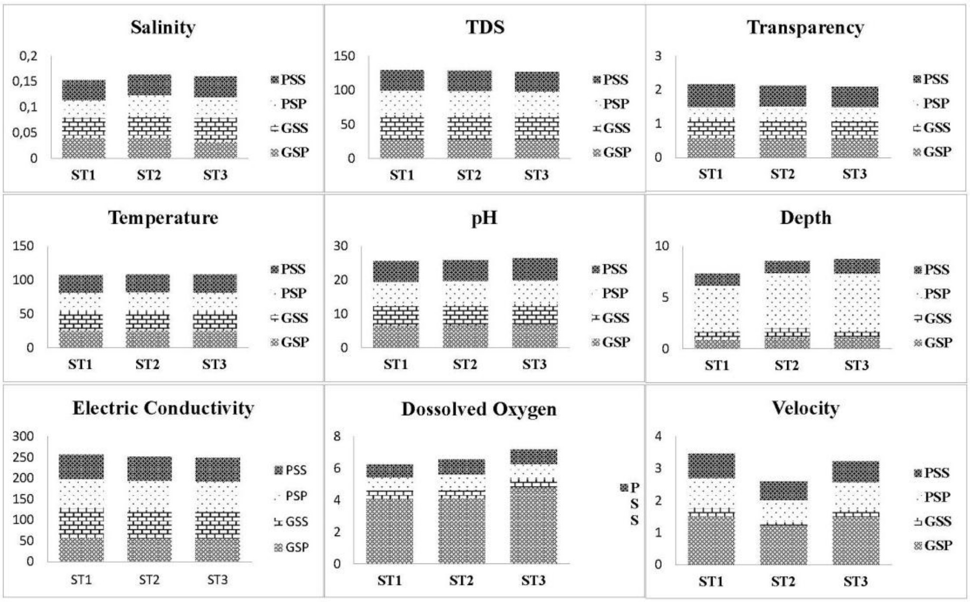

Fig. 2: Spatio-temporal variations of physico-chemical parameters in the waters of the Tovè River

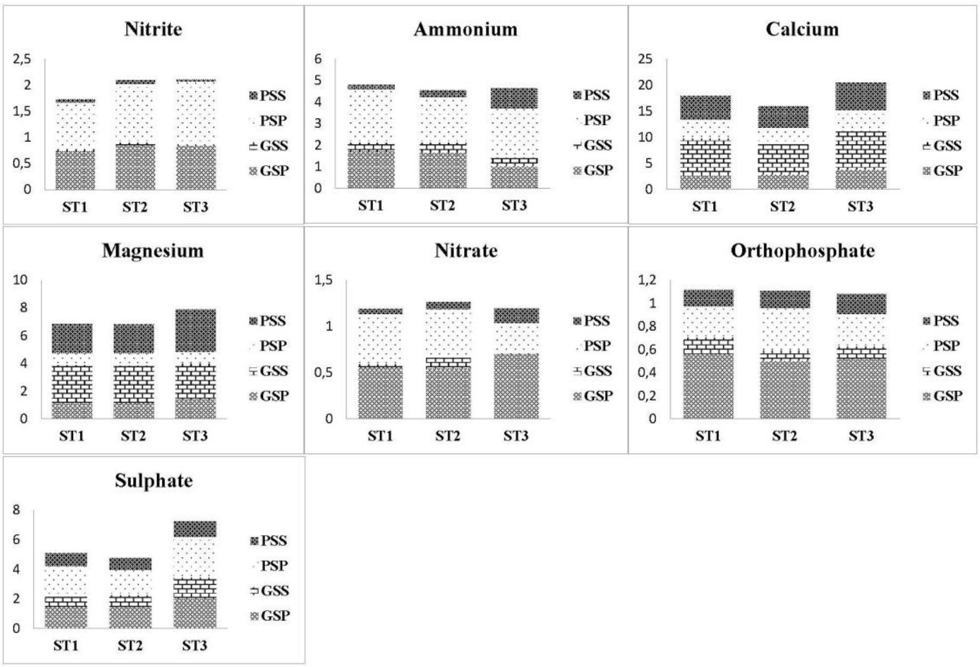

Fig. 2: (Continued)

Average phosphate levels remained almost the same across the river (0.28 and 0.27 mg/L, respectively, upstream, middle and downstream). The waters of the Tovè River are richer in these nutrient salts during the rainy seasons (Table 2 and Fig. 2). Two of the three parameters (nitrite and phosphate) exceed the standards for the protection of aquatic life. These values constitute a danger for fish because water containing nitrites can be considered suspicious or even toxic, even for fish at low doses according to Vissin *et al.*[14].

Correlation between physico-chemical parameters

The Bravais Pearson correlation analysis performed between the various physico-chemical and parameters is presented in Table 3. This analysis shows that the transparency parameter is positively correlated with the depth (0.85) and negatively with the conductivity (- 0.70) and ammonium (-0.70). As for the depth, it is positively correlated with ammonium (0.73). Otherwise, the temperature is positively correlated with conductivity (0.87) and TDS (0.91) and negatively with dissolved oxygen (-0.71) and velocity (-0.75). The latter (velocity) is positively correlated with the phosphates (0.75) and negatively with the calcium ion (-0.71). Dissolved oxygen and conductivity are correlated positively in turn with the current velocity (0.84), phosphates (0.80) and TDS (0.98), respectively. Magnesium is positively correlated with calcium ion (0.70) and negatively with ammonium (-0.82) nitrite (-0.84). This table also indicates that ammonium is positively correlated with nitrites (0.78) positively correlated with nitrates (0.70) which in turn are also positively correlated with phosphates (0.75). Finally, there is a strong positive correlation between pH and nutrient salts (0.74 with nitrates and 0.77 with nitrites) and sulphates (0.77).

Table 3: Matrix of correlations of the different parameters measured during the study period

	Trans	Prof	Temp	pH	Sali	Cond	TDS	O2	Vite	Mg^{2+}	Ca^{2+}	NH_4^+	NO_2^-	NO_3^-	PO_4^{3-}	SO_4^{3-}
Trans	1															
Prof	**0.85*****	1														
Temp	-0.44	0.29	1													
pH	-0.54	0.61	-0.15	1												
Sali	0.31	-0.22	0.28	-0.36	1											
Cond	**-0.70*****	0.59	**0.87*****	0.10	0.14	1										
TDS	-0.66	0.55	**0.91*****	0.05	0.15	**0.98*****	1									
O2	0.18	-0.26	**-0.71*****	0.35	-0.34	-0.61	-0.63	1								
Vite	-0.06	0.10	**-0.75*****	0.48	-0.49	-0.49	-0.54	**0.84*****	1							
Mg^{2+}	0.58	-0.61	0.23	-0.59	0.42	-0.12	-0.09	-0.39	-0.63	1						
Ca^{2+}	0.18	-0.33	0.55	-0.53	0.47	0.28	0.32	-0.52	**-0.71*****	**0.70*****	1					
NH_4^+	**-0.70*****	**0.73*****	-0.057	0.69	-0.34	0.27	0.25	0.24	0.49	**-0.82*****	-0.53	1				
NO_2^-	-0.64	0.68	-0.13	**0.77*****	-0.38	0.20	0.14	0.41	0.55	**-0.84****	-0.60	**0.78*****	1			
NO_3^-	-0.38	0.32	-0.35	**0.74*****	-0.43	-0.12	-0.15	0.68	0.69	-0.60	-0.58	0.63	**0.70*****	1		
PO_4^{3-}	-0.11	0.10	-0.51	0.48	-0.36	-0.32	-0.35	**0.80*****	**0.75*****	-0.62	-0.56	0.54	0.63	**0.75*****	1	
SO_4^{3-}	-0.56	0.59	0	**0.77*****	-0.27	0.20	0.16	0.25	0.39	-0.46	-0.23	0.59	0.64	0.57	0.30	1

Trans = Transparency, Prof = Depth, Temp = Temperature, Sali = Salinity, Cond = Conductivity, O_2 = Dissolved Oxygen, Mg^{2+} = magnesium ion, Ca^{2+} = calcium ion, NH_4^+ = ammonium ion, NO_2^- = nitrite ion, NO_3^- = nitrate ion, PO_4^{3-} = orthophosphate, SO_4^{3-} = sulphate ion, KW = Kruskal-wallis, NS = not significant, = Significant, ** = very significant and *** = highly significant

Influence of seasonal fluctuations on the dynamics of the physico-chemical variables of the Tovè River

According to the principal component analysis carried out (Fig. 3), two axes are sufficient to explain all the information at the level of 86.8%. Concerning the physico-chemical parameters of water, the axis 1 opposes the high concentrations of Mg^{2+} and Ca^{2+} with high concentrations of water in nitrogenous nutrients and to a rise of the pH. It appears that the dynamics of the physicochemical variables of the river indicate that waters with high levels of nitrogenous nutrients are accompanied by an increase in pH with a decrease in the contents of Mg^{2+} and Ca^{2+}.

Axis 2 opposes water of high dissolved O_2 and high transparency to waters with high depths, conductivities and high TDS. Thus, in the Tovè River, high transparency waters have high levels of dissolved oxygen with shallow depths correlated with a decrease in temperature.

With regard to the seasonal influence on the dynamics of the physico-chemical parameters of the Tovè River, it appears that the major rainy season is characterized by water with high dissolved O_2 and high transparency correlated with a decrease in mean temperature. On the other hand, the major dry season shows water concentrated in Mg^{2+} and Ca^{2+} and slightly concentrated in nitrogenous nutrients correlated with a decrease of pH. The minor rainy season marked by an increase in nitrogenous nutrients correlated with an increase in pH, however, indicates a decrease in certain nutritive salts such as magnesium and calcium.

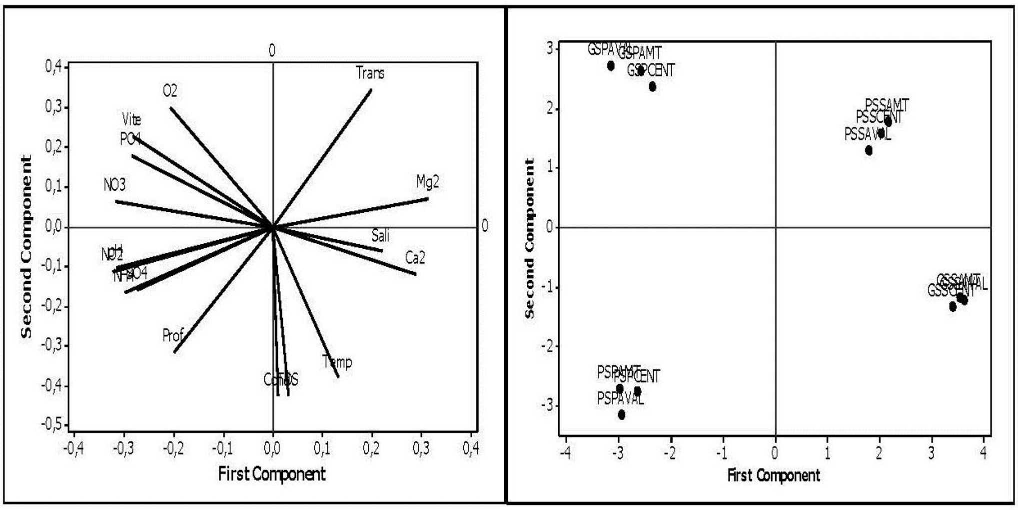

Fig. 3: Influence of seasonal fluctuations on the dynamics of the physico-chemical parameters of the Tovè River

DISCUSSION

The physico-chemical variables surveyed have a homogeneous distribution ($p > 0.05$) during the different seasons. This homogeneity could be explained by the shallow depth of this river, which favors the mixing of surface waters and bottom waters. This appears to be a particularity of tropical waters because small spatial variability of temperature and pH have also been observed in tropical estuarine waters by [15 - 17]. Moreover, the quality of the waters of this river is characterized by very marked seasonal variations of the parameters surveyed. These results are similar to those recorded in other Beninese rivers, such as those of [18, 19] in Ahémé Lake, [20] in the Ouémé River, [21] in Nokoué Lake, [22] in the Pendjari River, and [23, 24] in the Lagoon of Porto-Novo.

Indeed, the seasonal temperature measurements of the Tovè River indicate a variation between 25.81 °C recorded during the main rainy season and 28.15 °C during the major dry season. These data agree with the assertion of [25] according to which in intertropical Africa, average temperatures are high and usually above 20 °C. Current results are also similar to those of [26] where the average water temperature in the tropical wet zone is 30 °C.

Analysis of temporal variation in temperature showed higher values in the dry season than in the rainy season for the entire river. The values obtained by [20] on the Ouémé River which communicates with the Tovè River in its downstream part, show similar variations as reported in current studies. This seasonal variation in the temperature of the Tovè River is related to seasonal variations in atmospheric temperature and lighting conditions. Indeed, during the dry season the temperature of the air related to the solar radiation increases and in the rainy season it decreases with a covered weather. This variation in the atmospheric temperature influences the temperature of the water and causes the above mentioned variations

The water pH determines the acidity or the basicity of this water. It summarizes the stability of the equilibrium established between the different forms of carbonic acid and is linked to the buffer system developed by carbonates and bicarbonates [27]. The mean seasonal pH values measured in the Tovè River range from 6.08 during the dry seasons to 6.94 during the rainy periods. These waters are therefore slightly acid in the dry season than in the rainy season. According to [28] and [29], optimum pH conditions are obtained for values close to neutrality or slightly alkaline. This indicates that the pH of the waters of the river Tovè is in a good range for fish. Also, in the Brussels region, it is generally accepted that a natural pH between 6.5 and 8.5 characterizes waters where life occurred optimally. The increase of this parameter during high water, that is to say during the rainy season, is attributable to the water dilution effect which occurs during this period. These values are comparable to those observed by [20] but different from those observed by [30], who found rather low values during the rainy seasons respectively for the Ouémé River and the Pendjari River in Benin. The conductivity permits a better appreciation of the chemical richness of the corresponding environment [31]. It makes it possible to evaluate rapidly the degree of mineralization of water organic matters.

The mean conductivity of the waters of the Tovè River oscillates between 56.68 µS / cm and 70.27 µS / cm. This conductivity value is close to that observed by [32] in the Comoé National Park (44.55 µS / cm at 58.33 µS / cm) and much lower than those observed by [20] on the Ouémé River (mean value 99.8 µS / cm). The results of this study indicate a weak mineralization of the waters organic matters of the Tovè River. Compared with the seasons, the analysis showed high values of conductivity in the rainy season. This increase in conductivity is related to the proximity of village plantations and is attributable to rainfall runoff that drains physicochemical pollutants into aquatic systems. Also the irregularity of the flows could explain this variation as already stressed by Lévêque *et al.*[33].

Dissolved oxygen concentrations together with pH values are one of the most important water quality parameters for aquatic life[34, 9].

The average seasonal rate of dissolved oxygen in the Tovè River varies between 0.50 mg/L recorded during the major dry season and 4.35 mg/L during the major rainy season. Several phenomena such as atmospheric oxygen partial pressure, water temperature, salinity, light penetration, water agitation and nutrient availability could be to the origin of this fluctuation. On the other hand the rates of dissolved oxygen observed could be also function of the speed of impoverishment of the area in oxygen by the aquatic organism activity and the processes of oxidation and decomposition of the organic matter present in water. Indeed, the excessive growth of algae and macrophytes can also lead to very significant oxygen drops and cause a significant release of the phosphates trapped in the sediment, thus aggravating eutrophisation problems[35].

Like transparency, TDS, the average depths of the stream bed and the low average velocity are recorded during dry periods. The maximum values of these parameters are reached during the rainy seasons. [36] made the same observations on coastal rivers in the south-east of Cote d'Ivoire. These temporal variations in depth, transparency, TDS and current velocity could be explained by the phenomena of flood and subsistence associated with the dry and rainy seasons.

The levels of phosphates, nitrates and nitrites, as well as ammonium and sulphate, are relatively high in the Tovè River during the rain and flood seasons, contrary to the contents in Magnesium and calcium. During these periods, drainage of runoff and watersheds are the source of anthropogenic nutrient intakes [37]. The upstream areas of the Tovè River are largely covered by rice crops and market gardens and by others through aquaculture. The use of nitrogen fertilizers in these cultivated areas, drained by runoff, would lead to water nitrification. Similarly, the use of phosphate fertilizers enriches the waters with orthophosphates which prevent the formation of calcium complexes inhibiting biological precipitation of calcite [38]. The results from the two other variables, magnesium and calcium, could be attributed to large amounts of detritus remineralized by high dry season temperatures [39]. These salts are increasingly diluted by runoff water loaded with detrital particles resulting from soil erosion which disturb the waters generating the low values of transparency recorded during the study. To these phenomena is added the fact that riparian populations and animals defect directly or indirectly in the waters. Indeed, as a result of anthropogenic activities, chemicals released into the environment can enter aquatic ecosystems, causing their progressive pollution, which constitutes a danger for biocenosis.

CONCLUSION

The results generated from the Tovè River show that the waters of this river are highly oxygenated, close to neutrality and strongly mineralized with high levels of dissolved salts (nitrites, nitrates, phosphates, ammonium and sulphate) during periods of flood or rain. These values compared to the Criteria for the Protection of Aquatic Life, revealed that fishes from the Tovè River are not in a secure environment that guarantees their survival and sustainability. Efforts must be done by the authorities of the surrounding municipalities of the river for the integrated management of this ecosystem threatened by chemicals drained by runoff.

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