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Modeling of Dissolved Oxygen (O_2) Dynamics on the Left Bank of the Congo River; Port Ex Onatra River City

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Abstract

The water quality of the Congo River is affected by industrial discharges. In this study, the evaluation of their impact was carried out using a mathematical approach. Used as water quality management tools, mathematical models are developed through an iterative process. The Streeter-Phelps model was used as a base model, and the methodological approach was that of Eckenfelder. This consisted of a campaign of parameter measurements that influence the dissolved oxygen content, a statistical treatment of data, a determination of the different global kinetic constants (K_1 and K_2) and the evaluation of the model by the Nash criterion. The results obtained are 2.26 j^{-1} and 13.26 j^{-1} respectively for the K_2 reaeration and deoxygenation K_1 constants; 498 mg / L for the initial oxygen biochemical demand (L_0) and 3.82 mg / L for the initial oxygen deficiency (OD); 1.4767 j^{-1} for the degradation constant of the organic matter k_d and 1.000621805 for the ratio α ($L_0/L_{(5)}$); generated a theoretical dissolved oxygen profile different from the experimental profile but which nevertheless allowed to simulate the fluctuations of the dissolved oxygen with the organic load. The statistical processing of the data has increased the reliability of the measurement campaign. The low value found for the Nash criterion (0,1756506) showed that this model should be adjusted to better evaluate the oxygen content.

Key words: management ; evaluation ; industrial discharges ; reaeration ; deoxygenation.

1. Introduction

According to the reports of the United Nations Environment Program (UNEP), the Democratic Republic of Congo (DRC) has a low water supply [1] while it has the second largest watershed important in the world, the Congo Basin [2].

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The use of surface water for domestic, agricultural, fish and other uses is very common. Thereby ; the quality of surface waters, especially those of the Congo River, is of crucial importance for the country [3,4]. Unfortunately in some respects, anthropogenic activities alter the quality of the latter restricting its uses ([31,33]). This deterioration is due to an overload of organic matter of agrifood and domestic origin, to toxic substances coming from agricultural and industrial activities [5,11]. The section of the Congo River from the Cité du fleuve to the SCPT port (formerly Onatra) in Kinshasa concentrates a few agro-food companies (breweries, lemonades, flour mills, etc.), emptying septic tanks and a few river ports that pour their water directly into it. used with or without treatment affecting the quality of the water [6, 7]. Doulaye reveals in his work, that nearly 78% of African cities did not have any formal service of evacuation and wastewater treatment [6].

Assessment of stream quality is done through a key parameter, the dissolved oxygen content, whose role for aquatic life and the health of the population is important [8, 12, 28]. This parameter makes it possible to estimate the conditions of pollution, of the degradation of the discharges and the self-purifying capacities of a watercourse [9, 10, 33]. In the Democratic Republic of Congo, this evaluation is very often done using a descriptive approach which consists of analyzing a certain number of physical, chemical and biological parameters which describe the good ecological state and comparing the values obtained with the target values called norms [10, 11].

Streeter and Phelps have developed a mathematical relationship that allows the assessment of surface water quality by the profile of dissolved oxygen; this is a function of the degradation level of the organic matter and the rate of diffusion of oxygen between / at the water-atmosphere interface [12, 13,14, 15, 32]. The Streeter-Phelps model was used as a basic model in the iterative process of developing a water quality model for the left bank of the Congo River (Kinshasa).

This simple model is a forerunner of current river quality models [10]. Eckenfelder is one of the researchers who has used the Streeter-Phelps model extensively to determine the oxygen profile of several rivers and whose approach inspired us to evaluate the global impact of industrial discharges on this section [3, 5, 12, 13, 16]. The statistical evaluation of the data was made to assess the degree of reliability of the measurement campaign before the determination of the global kinetic constants, followed by the profile determination by the Excel software and finally the evaluation of the model obtained by the criterion of Nash.

The results obtained could contribute to the optimal management of the Congo River, which is increasingly subject to increasing anthropic pressure.

2. Material and methods

2.1. Experimental site and sampling

The measurement campaigns were carried out during the low-water period (August and September 2015 and 2016) at a frequency of two samples per month.

The samples were taken immediately 30 cm from the surface and about 100 meters off the left bank of the

Congo River (Kinshasa) with coordinates at the starting point latitude 4 ° 19'37.6 " and longitude 15 ° 20'58.0 " and at the point of arrival latitude 4 ° 17'49.6"and longitude 15 ° 19'13.3 ". Two samples were taken, upstream of the rejection point of a brewing enterprise rated EA (EA1 and EA2); and ten others downstream from the same point denoted EV (EVi, i = 1 to 10), in one liter flasks made of new and cleaned plastics (Figure 1).

These were stored in the cooler before being sent to the laboratories of the DRC's Regie (Regideso) and the Regional Postgraduate School of Integrated Management and Planning of Forests and Tropical Territories (ERAIFT). The sampling points were chosen according to their accessibility and their position, that is to say they are located downstream of all new discharges and in such a way that the dissolved oxygen content is not zero according to Eckenfelder [16] .

The GARMIN Global Positioning System (GPS), GPSMAP 78 series allowed the determination of the position and distance of each sampling point and the mapping of the site. Nylon wire with a weight and a graduated cane was used to measure the average depth of the water column on the section.

Figure 1: Experimental site [Cité du fleuve-Port SCPT (ex Onatra) in Kinshasa]

Legend: a. Map Democratic Republic of Congo b. Study area Cité du fleuve-Port SCPT (formerly Onatra) in Kinshasa c. Malebo Pool d. Map of the city of Kinshasa. PD Starting point, PR: Discharge point, PS: Ending point, EA: Upstream sample EV Downstream sample

2.2. Measurement campaign

The measurement campaign focused on parameters describing the state of oxygenation, organic pollution and nutrient loading [8, 10, 17, 18]. The parameters measured in situ and in the laboratory of Regideso and Eraift, the conditions of conservation of the samples, the methods of analysis [30] are shown in Table 1.

2.3. Statistical treatment of data

The statistical treatment of the results of the measurement campaign consisted of the determination and analysis of the correlation between the key variable of the model (dissolved oxygen) and the other variables measured. The existence of a relationship between dissolved oxygen and other variables, the form (or sense) of it (positive or negative, linear or nonlinear, monotonic or non-monotonic) and its intensity were determined by calculating the covariance $Cov(x, y)$ and Pearson coefficient $\rho_{(x,y)}$ estimated by calculating the correlation coefficient $r_{(x,y)}$. A strong link between variables results in a high value of covariance.

The Pearson test revealed whether there is a significant linear link [20].

Tableau 1: Parameters analyzed and methods used for modeling

Parameters	**References AFNOR / ISO**	**Conservation**	**Materials and Methods**
pH	NFT 90008	In situ	Portable pH Meter Pen Series Pen Meter (OHAUS)
Electrical conductivity	NFT 90031	In situ	Conductivity meter Waterproof HI 98311
Ammonium	NF T90-015-2	4°C	Nitroprusside sodium and phenol, NaOH (HACH); Spectrophotometry ; λ= 630 nm
Phosphates	NF EN ISO 6878	4°C	ammonium molybdate, antimony and potassium double tartrate, ascorbic acid, H2SO4; Spectrophotometry; λ = 700-800 nm
COD	NFT 90 101	4°C/ H_2SO_4	Acidic medium, $K_2Cr_2O_7$, $AgSO_4$, $HgSO_4$
BOD_5		4°C	Respirometry / BODTrak ™ II / HACH
T°			Sonde Conductivity meter and pH meter
O_2 dissous		In situ	Portable Oximeter / HI 9146 / Hanna, Electrochemical Methods
Nitrates	ISO 7890-3	4°C	sodium salicylate, disodium salt of ethylene diamine tetracetic acid, NaOH, H2SO4; sodium azide (Nitraver / HACH) / Spectrophotometry; λ = 415 nm
Nitrites	NFTEN 26777	4°C	Orthophosphoric acid; Diazotization reagent (4-aminobenzenesulfonamide and N- (1-naphthyl) 1,2-diamino ethane), H3PO4 (NitriVer / HACH) / Spectrophotometry; λ = 510 and 543 nm

The regression made it possible to check whether the variable (dissolved oxygen content), depended on the other variables or better predict the future values of y (dissolved oxygen) knowing the corresponding x (pH, NH_4^+ content, PO_4^{3-}, BOD_5, COD) [19, 22, 26].

The contribution of the different points to the regression was obtained by calculating $r^2_{(x,y)}$ [22]. The covariance, the Pearson coefficient and the correlation coefficient are calculated as follows:

$$Cov(x,y) = \frac{1}{n-1}\sum_{i=1}^{n}(x_i - \overline{x})(y_i - \overline{y}) \tag{1}$$

$$\rho_{(x,y)} = \frac{Cov(x,y)}{\sigma_x . \sigma_y} \tag{2}$$

$$r_{(x,y)} = \frac{\sum_i (x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum_i (x_i - \overline{x})^2 \left(y_i - \overline{y}\right)^2}} \tag{3}$$

Graphical analysis was used to visualize the shape of the connection, the proximity between the points, the overall shape of the points, and to detect the points that deviate from the others, to make the atypical observations and to check if there is any no suspicious groupings implying that there is in fact a third variable that influences the positioning of individuals.

The line for which is small indicates a strong dispersion of points with respect to the line [21, 22]. The significance test t was performed to check whether the links between the variables are linearly significant or not, and deduce if the amount of data is sufficient [19, 20, 22]. This test is an assessment of the reliability of the results of the measurement campaign.

2.4. Modeling proper

The construction of a model does not rest on a formal theoretical basis but rather on an iterative method consisting of carrying out successive tests and comparing field-collected data and models formulated in the symbolic domain [25].

The Streeter-Phelps model used considers that the fluctuations of dissolved oxygen in the aquatic environment are due solely to two phenomena: deoxygenation K1 and re aeration K2 [12, 13, 14, 15]. In modeling, the degradation of organic matter and the re-generation at the air-water interface are simulated by first-order kinetics [30, 32]. The methodological approach used to determine the overall kinetic constants of the section was that of Eckenfelder.

The oxygen deoxygenation constant K1 is obtained by measuring the biochemical oxygen demand (BOD, represented by L in the rest of this presentation) due solely to the biochemical oxidation of the organic matter) as a function of the distance traveled or the time. This degradation process is described by equation (1)

$$L_{(x)} = L_{0.}.e^{-\frac{K_1.x}{v}} \text{ or } \ln L_{(x)} = \ln L_0 - \frac{K_1}{v}x \qquad (4) \ ([13, 16, 24, 25])$$

L $_{(X)}$ is the organic charge at the distance X; L_0 the organic load at the point of departure and v the flow velocity. The graphical method according to Thomas made it possible to determine kd by plotting on a graph (t / y) $^{1/3}$ (L = y = biochemical oxygen demand) as a function of time t.

The line obtained made it possible to deduce the angular coefficient b and the ordinate at the origin has; and calculate kd as follows:

$$k_d = 6.\frac{b}{a} \qquad (5)$$

Experimental measurements make it possible to determine L $_{(5)}$. Knowing kd and L $_{(5)}$, L_0 is calculated using the relation:

$$\frac{L_0}{L_{(5)}} = \frac{1}{1-e^{-k_d.t}} = \alpha \qquad (6)$$

The consumption of oxygen during the degradation of organic matter creates a deficit (D) which is compensated at all times by atmospheric oxygen. The oxygen deficit is calculated as follows:

$$D_{(t)} = C_S - C_{(t)} \qquad (7)$$

With C (t): concentration of dissolved oxygen at time t and C_S the concentration of dissolved oxygen at saturation at temperature T.

The reaeration coefficient of the section k_2 has been calculated by the relation:

$$\ln D_{(t)} = \ln D_0 - k_2.t \qquad (8)$$

While the global constant of reaeration K_2 is obtained by making the ratio of the réaération coefficient k_2 by the average depth H of the section.

$$K_2 = \frac{k_2}{H} \qquad (9)$$

The variation of the kinetic constants with the temperature is expressed by the Van't Hoff equation:

$$k_{(t)} = k_{(20°C)}.\theta^{(T-20)} \tag{10}$$

With θ = 1,047 (Phelps), only for temperatures above 15°C [16,23] The determination of these kinetic constants, by the graphical method, required the elimination of the extreme or aberrant points after calculation of the residuals (residual differences between the measured y and the estimated by the regression) .The latter is calculated in the following way :

$$R_i = y_i - (mx_i + b) \tag{11}$$

A good correlation was obtained by eliminating the points (xi, yi) whose residues are greater than the average of squares of the residues [19, 21, 22].

The oxygen profile of the section is obtained by replacing the different kinetic constants in the Streeter-Phelps equation:

$$C_{(x)} = (C_S - D_{(x)}) = C_S - \left\{ \left[\frac{K_1.L_0}{K_2 - K_1} \right] \left(e^{-\frac{K_1.x}{v}} - e^{-\frac{K_2.x}{v}} \right) + D_0.e^{-\frac{K_2.x}{v}} \right\}$$

(12) [13, 14, 15, 24]

2.5. Assessment of the quality of the model

The modeling errors are the differences between the calculated values and the observed values. They were evaluated by determining the precision which translates the dispersion of the modeling errors εi by the Nash criterion [32] as follows:

$$CN = 1 - \frac{\sum \left(y_i - \hat{y} \right)}{\sum \left(y_i - \hat{y} \right)^2} \tag{13}$$

With observed (or experimental) values and values calculated by the relation (12). When the adjustment between simulated and observed values is perfect CN = 1 while CN is negative when the model gives poorer results.

3. Results and discussion

3.1. Results of the measurement campaign

The measurement campaign gave the results shown in Table 2:

Tableau 2 : Results of the measurement campaign (august-september 2015 and 2016)

Samples	Distance (Km)	pH	T (°C)	Conductivity (µs/cm at 20 ° C)	dissolved O_2 (mg / L)	COD (mgO_2 / L)	BOD_5 (mgO_2 / L)	NH_4^+ (mg/L)	Ptotal (mg/L)
EA1	0,0	7,40±0,12	25,9±1,1	38,4±1,5	4,07±0,73	1022±20	498±10	10,24±1,12	9,23±1,11
EA2	1,7	7,30±0,11	26,1±1,0	36,4±2,1	3,89±0,73	780±14	390±15	8,94±1,22	5,78±0,49
Ebrute	3,8	12,55±0,25	28,60±0,61	14850,00±1200,51	0,84±0,12	1393,0±5	697±3	27,18±2,32	14,98±1,32
EV1	3,9	8,14±1,22	26,1±1,2	45,3±6,4	2,12±0,59	978±12	481±8	16,47±1,42	9,97±1,22
EV2	4,1	7,48±0,25	26,1±1,2	57,3±18,3	5,56±0,79	1185±18	653±8	5,64±0,65	6,22±1,11
EV3	4,2	7,22±0,27	26,0±1,1	40,5±13,8	5,29±0,65	11051±34	536±17	5,37±0,67	5,86±0,87
EV4	4,4	7,23±0,20	26,1±1,4	32,8±3,1	5,44±0,78	930±13	490±8	11,76±1,32	7,38±1,14
EV5	4,7	7,16±0,23	26,3±1,2	31,2±1,7	5,62±1,02	854±13	417±14	15,23±1,34	9,04±2,02
EV6	4,9	7,15±0,22	26,0±1,4	31,6±2,2	5,72±1,09	716±16	274±8	5,03±0,45	5,45±1,09
EV7	5,1	7,17±0,15	26,2±1,4	32,9±4,0	5,91±0,90	658±7	349±5	4,32±0,56	4,89±0,89
EV8	5,3	7,17±0,11	26,0±1,5	35,4±5,5	5,72±0,73	601±12	332±13	4,26±0,63	4,6±0,32
EV9	5,4	7,08±0,24	26,3±1,2	33,2±2,8	5,88±0,78	570±43	308±23	3,91±0,51	4,58±0,44
EV10	5,6	7,27±0,20	26,3±1,3	33,6±2,6	6,41±1,02	511±49	276±27	3,74±0,45	4,32±0,25
Norm sewages *		6–9	<35°C			< 500	<300		
Norms waters of surface * *		6,5-8,5				0–20	3 mg/L	0,5 mg/L	0,02 mg/L

Legend :* :

**** :**

3.2. Results of the correlation analysis

3.2.1 Analysis of covariance and correlation coefficient

Table 3: Statistical Processing of Data

N°	Variables X-Y	$Cov(x,y)$	$r_{x,y)}$	$r^2{}_{(x,y)}$
1	pH- O_2 dissous	-0,50521515	-0,83943	0,7046
2	Cond- O_2 dissous	-5,65878788	-0,35541	0,169
3	Min- O_2 dissous	-7,9936 10^{-15}	-0,38168	0,1457
4	COD - O_2 dissous	-184,939091	-0,44199	0,0171
5	BOD_5-O_2 dissous	-76,2465152	-0,35789	0,4928
6	NH_4^+ -O_2 dissous	-6,39918636	-0,68594	0,4928
7	PO_4^{3-}- O_2 dissous	-2,52228333	-0,70201	0,4928

The results recorded in this table show that:

- The calculated covariance values are all negative, which implies that a negative linear bond, that is to say that the increase of the variable (COD, BOD_5, PO_4^{3-}, NH_4^+ ...) in the abscissa is accompanied by a drop in dissolved O_2 content, ordinate.
- The values for COD and BOD_5 with dissolved oxygen are high. In other words, the increase in COD and BOD_5 is accompanied by a significant decrease in dissolved O_2 content. The relationship or bond between the dissolved O_2 and these two parameters is stronger. This decrease in dissolved oxygen is lower for the other variables.
- However, the correlation coefficient gave high values for ammonium and phosphate involving a strong bond between these parameters and dissolved oxygen, and a statistically linear link. Which was not the case with COD and BOD_5
- The coefficient of determination calculated for the pair of dissolved pH-O_2 variables is higher than the coefficient of determination of the other pairs of variables. The value obtained for the pH shows that 70.46% of the values found make it possible to explain the O_2 variation with the pH, conversely. The values of 0.4928 for dissolved PO_4^{3-}-O_2, dissolved NH_4^+ -O_2 and dissolved DBO_5-O_2 simply reflect the fact that almost half of the values found, ie only 49.28%, explain the link between these variables and the dissolved oxygen content.
- Very low values of $r^2_{(x,y)}$ (<0.2) for dissolved T-O_2 couples, dissolved O_2-mineralization, dissolved O_2-Conductivity and dissolved COD -O_2 imply that few results (less than 20%) can explain the intensity and direction of the connection.

3.2.2. Graphical Analysis

Graphical analysis with Excel software has led to the figures below:

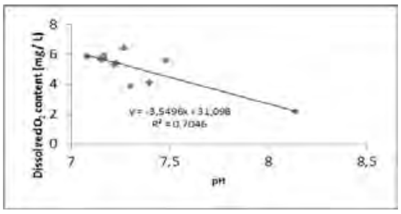

Figure 1: pH and dissolved O_2 correlation

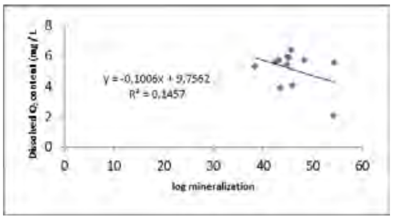

Figure 2 : Mineralization and dissolved O_2 correlation

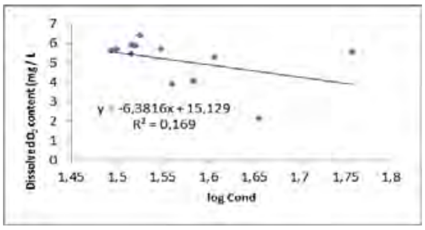

Figure 3: Conductivity and dissolved O_2 correlation

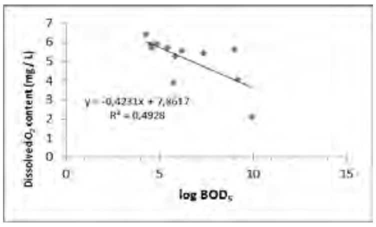

Figure 4: Organic load and dissolved O_2 correlation

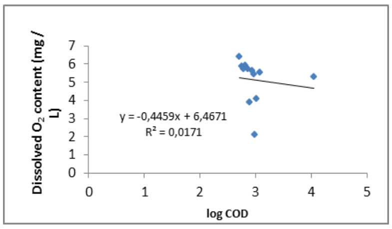

Figure 5: COD and dissolved O_2 correlation

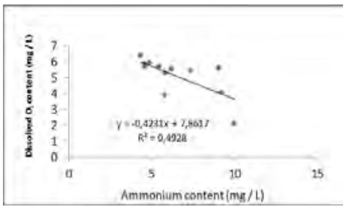

Figure 6: NH_4^+ and O_2 dissolved correlation

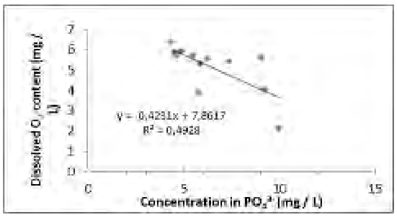

Figure 7: Phosphorus and dissolved O_2 correlation

Figures 3, 4 and 5 show a strong dispersion of the points which affect the regression (with $R^2 = r^2$) compared to the other figures. These results confirm those calculated from Table 2. However, covariance alone better illustrates the relationship between biochemical demand, chemical oxygen demand and dissolved oxygen.

3.2.3. Significance test t

The results of the statistical test t show that the pairs of pH-O_2, NH_4^+-O_2 and Ptotal-O_2 variables have statistically significant linear links compared to the other pairs. This could be due to the sampling method, conservation or method of analysis of these parameters. Special and sustained attention should be given to the measurement campaign. The creation of Congo River quality monitoring stations is a necessity to build a reliable and up-to-date database.

Table 4: Results of the significance test t

Parameters	Correlation coefficient $r_{(X, Y)}$	test t	$\lvert t \rvert$	t_{seuil}	**Conclusion** **$\lvert t \rvert >$ tseuil for α = 0,05 (risk 5%), dismissal of the hypothesis H0 càd not**
pH-O_2	-0,839422313	-4,884242122	4,884242122	2,228	H_0 rejection, existence of a linear link statistically significative
COD -O_2	0,006301546	0,019927632	0,019927632	2,228	No H_0 rejection, no statistically significant linear link
BOD_5-O_2	-0,357894035	-1,212043391	1,212043391	2,228	No H_0 rejection, no statistically significant linear link
NH_4^+-O_2	-0,685944604	-2,981015702	2,981015702	2,228	H_0 rejection, existence of a linear link statistically
Ptotal-O_2	-0,702006464	-3,117145589	3,117145589	2,228	H_0 rejection, existence of a linear link statistically

3.3. Determination of kinetic constants

The physicochemical side of the modeling was the determination of the constants K_1, K_2, Lo and Do of the section [12, 25, 27]. This was done according to the Eckenfelder approach which uses the graphical method [16]

3.3.1. Determination of the kinetic constant of degradation of the organic matter kd and the ratio α

The determination of the kinetic constant of degradation of the organic matter kd was made by the graphical method of Thomas. It consisted in measuring the L (BOD) of at least one sample taken at random for 7 days in the bottle. BOD and then graphed $(t / y)^{1/3}$ as a function of time (t). Note that y represents L (BOD) and t is time. The results obtained are shown in Table 5 and in Figure 9:

Table 5: L (or BOD) as a function of time (day)

Temps, t (jour)	L (mg O_2/L)	(t/y)(L=y)	$(t/y)^{1/3}$
1,0	239	0,00418	0,16110
2,0	222	0,00901	0,20810
3,0	211	0,01422	0,24220
4,0	208	0,01923	0,26790
5,0	205	0,02439	0,29000
6,0	202	0,02970	0,30970
7,0	200	0,03500	0,32710

From the equation of the line y = 0.0268x + 0.151 (of the form y = bx + a), we deduce a and b in order to calculate k_d by the relation (5), 1.064900662 j-1 at 20 ° C and 1.47670113 at 26 ° C by the relation (10). Eckenfelder asserts that when k_d > 0.15 d-1, the discharges are unpurified, while for k_d <0.10 d-1, the effluents are purified [16]. In view of this assertion, the waters of the section of the left bank of the Congo River (Kinshasa) are unpurified since kd = 1.064 d-1 > 0.15 d-1 and therefore very rich in organic matter. The value of kd and the experimental time to measure BOD_5 (t = 5 days) made it possible to calculate the ratio between the organic load at the start of the degradation process in the BOD (L_0) flask and that remaining after 5 days. ($L_{(5)}$) using the relation (6): $\alpha = L_0 / L_{(5)} = 1.000621805$. The value of α gives the possibility of knowing the quantity of initial organic matter L_0.

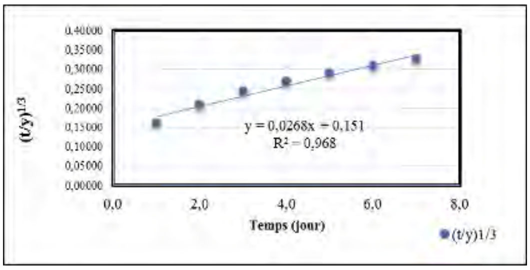

Figure 9: $(t / y)^{1/3}$ as a function of time (t)

3.3.2. Determination of the global deoxygenation constant K_1

The determination of K_1 was made by plotting on graph ln BOD_5 (kg / d) as a function of the distance traveled x (Km).

Table 6: Conversion of BOD_5 (mg / L) to BOD_5 (kg / d) and calculation of residues

Xi				yi (mesuré)	Ri	
Distance traveled (Km)	Débit m^3/sec	BOD_5 mg/L	BOD_5 kg/j	ln BOD_5 kg/j	Résidus	R_i^2
0,0	41000,0	498	1764115200	21,2909151	-0,049084901	0,002409328
1,7	41000,0	390	1381787234	21,0466436	-0,115026405	0,013231074
3,9	41000,0	481	1703894400	21,25618229	0,325292292	0,105815075
4,1	41000,0	362	1282939200	20,97241953	0,062509533	0,003907442
4,2	41000,0	232	821836800	20,52705239	-0,370584307	0,137332728
4,4	41000,0	428	1516737600	21,13982755	0,264849249	0,070145125
4,7	41000,0	483	1710979200	21,26033168	0,408116675	0,166559221
4,9	41000,0	305	1081848960	20,80193741	-0,027514286	0,000757036
5,1	41000,0	297	1050675840	20,77269945	-0,034093849	0,001162391
5,3	41000,0	287	1015960320	20,73910013	-0,05017487	0,002517518
5,4	41000,0	254	898352640	20,61607324	-0,153270756	0,023491925
5,6	41000,0	228	808375680	20,51053746	-0,240973541	0,058068247
						Average R_i^2
						0,048783092

The line obtained, y = 21.282-0.1033x, is identical to equation (1) which describes the degradation of organic matter.

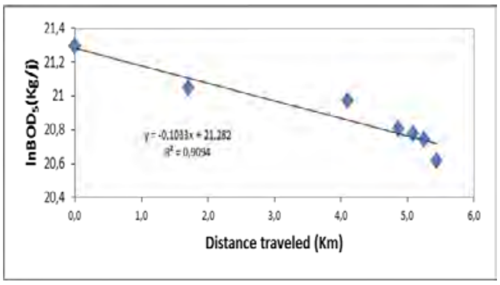

Figure 10: Determination of J_1 by carrying ln BOD_5 (kg / d) as a function of distance traveled

From this line, the ratio is 0.1033 Km^{-1} at 20 ° C and 0.1432 Km^{-1} at 26 ° C. K_1 is 12.03 d^{-1} at 26 ° C for an average flow rate of 3.5 Km / h.

3.3.3. Determination of the overall kinetic constant of K_2 reaeration

The transfer coefficient k_2 was determined by comparing the line, y = 1.0913 - 25.37x, obtained by carrying lnD as a function of time t as illustrated in FIG. 11 to expression (8). K_2 is calculated using relation (9). For an average depth of 10 m, the value of K_2 is 2.54 d^{-1}. Tableau 7 Dissolved Oxygen vs. Time and Deficit Calculation

Table 7

Xi			Yi		
Time in (min)	Time in (day)	D=Cs-C	lnD	Ri	R_i^2
5	0,003472222	5,22	1,65	-0,16891649	0,02853278
10	0,006944444	7,75	2,05	0,3149801	0,099212461
15	0,010416667	5,58	1,72	0,0754637	0,00569477
20	0,013888889	4,28	1,45	-0,10267033	0,010541196
25	0,017361111	4,10	1,41	-0,05680773	0,003227118
30	0,020833333	4,05	1,40	0,02040672	0,000416434
35	0,024305556	3,91	1,36	0,07395314	0,005469067
40	0,027777778	3,55	1,27	0,06450303	0,004160641
45	0,03125	2,91	1,07	-0,04431512	0,001963829
50	0,034722222	2,15	0,77	-0,25853799	0,066841892
55	0,038194444	2,27	0,82	-0,11750743	0,013807996
60	0,041666667	2,10	0,74	-0,10660563	0,011364759
65	0,045138889	2,24	0,80	0,04466067	0,001994576
70	0,048611111	2,14	0,76	0,09087893	0,008258979
75	0,052083333	2,12	0,75	0,16998631	0,028895344
			Y_{moy}		Average R_i^2
			1,20		0,01935879
			σ		
			0,42111898		

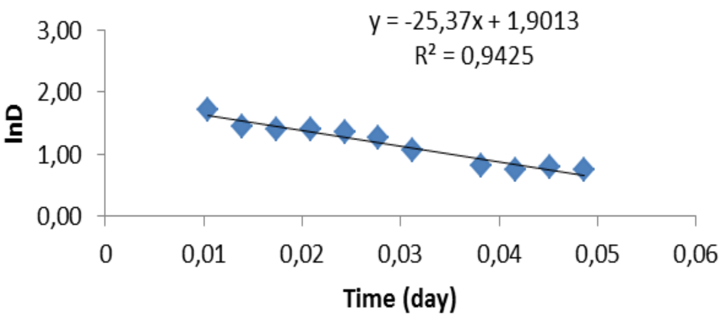

Figure 11: Determination of K_2 by carrying lnD as a function of time (days)

The value obtained is in the range of 2.0-3.0 d^{-1} and corresponds to the reoxygenation coefficients of large rivers or rivers with moderate velocities according to Ugberbor [15].

3.4. Oxygen profile

The expression of the dissolved oxygen on the section, after calculations of the different kinetic constants, is the following one:

$$C_{(x)} = (C_S - D_{(x)}) = 1{,}205 L_0 \left(e^{-\frac{13{,}26x}{v}} - e^{-\frac{2{,}26x}{v}} \right) - (C_S - C_0) e^{-\frac{2{,}26x}{v}} + C_S \tag{14}$$

From expression (14), the distance at which the dissolved oxygen concentration is critical (almost zero) Xc and its Dc value were calculated as follows:

$$x_c = \frac{v}{11{,}004} \ln \left\{ 0{,}1704 \left[1 - \frac{11{,}004(C_0 - C_S)}{13{,}26 L_0} \right] \right\} \tag{15}$$

$$D_c = 5{,}8673 L_0 e^{-\frac{2{,}26x}{v}} \tag{16}$$

where x_c: distance at which the concentration of dissolved oxygen is critical (almost zero); C_S: dissolved oxygen content at saturation; C_0: dissolved oxygen content at the point of departure and $C_{(x)}$ the dissolved oxygen content at the distance x from the starting point; Dc: Oxygen deficit at the critical point x_c, x and v are respectively the distance traveled and the speed . Equation (14) and the Excel software gave the following profile:

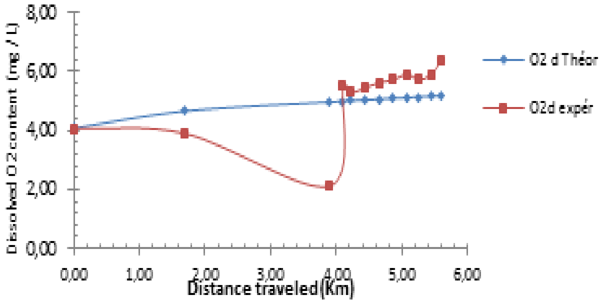

Figure 12: Dissolved O_2 profile of the section

This theoretical profile shows that the oxygen content varies between 4.08 and 5.18 mg / L on this section while the experimental profile reveals a content of 4.08 mg / L dissolved O_2 at the start and a maximum value of 6.41 mg / L of dissolved O_2 downstream with a minimum of 2.12 mg / L of O_2 dissolved at 3.9 Km of the path. Equations (15) and (16) allow us to say that the distance at which we will have a critical oxygen deficiency (= 0.34 mg / L) is 13.64 Km. Equation 10 also made it possible to simulate the variation of dissolved oxygen as a function of the organic load. The results obtained are illustrated in figure. 13:

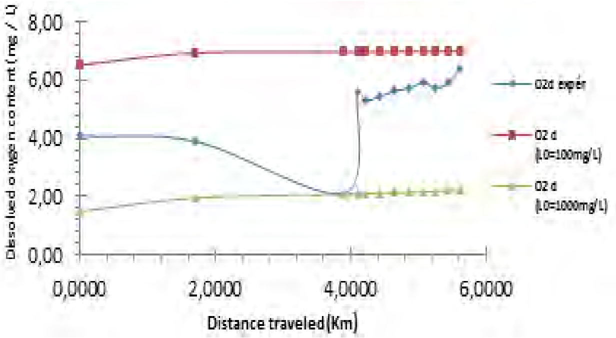

Figure 13: Variation of dissolved O_2 as a function of organic load

The higher the organic load at the point of departure, the greater the oxygen deficiency. The self-purification factor calculated for the section is 4.74; value close to that of torrents according to Cluis D. [25] but this can be affected by the morphology and the nature of the effluents.

3.5. Evaluation of the quality of the model

The Nash criterion calculated by relation (13) gave the value of 0.1756506. This indicates that the adjustment between simulated and observed values is unsatisfactory. The two curves therefore have different and marked paces. These differences, relative to the theoretical profile, reveal the simplicity of the Streeter-Phelps model which does not integrate the physical phenomena (diffusion and dispersion: description of the movements of the masses) [29] and the biomass of the studied section (origin, quantity, type and special distribution of organic matter) [8, 24, 26, 31] but also the amount of input data as shown by the statistical results.

Cluis, in his work had shown that the assumptions emitted by Streeter-Phelps discard several factors that influence the level of dissolved oxygen in a watercourse. As a result, this model can only be used, at best, for preliminary estimates of the response of a watercourse to organic loads [24]. This corroborates with the results obtained. These deviations are also to be found in the morphology and the composition of the benthic bottom of the section which varies with the heterogeneity of the organic matter present in the medium [18, 24, 29]. The low value of the Nash criterion (0,1756506) confirms the results obtained. Eckenfelder also states that the size and age of the companies on this section determine the flow and characteristics of wastewater; and the quality of the receiving waters [18]. Edeline adds that the complexity of situations (reconciliation of discharge points, tributaries, diversity of port activities, etc.) is difficult to model, and as a result forecasts are rarely very accurate. According to Sophie S. and his colleagues the predictive aspect of modeling, although sought after, is not necessarily the most available because of the amount of input data that it imposes and the impossibility of strict verification [10].

The statistical test has shown that the correlation coefficient $r_{(x,y)}$ Pearson is -0.35789 for the pair of dissolved BOD_5-O_2 variables, an important parameter of the model. This value actually shows that the content of dissolved O_2 varies inversely with the but the intensity of this relationship is low in our case. The reason for these discrepancies is the sampling technique and the amount of data. Continuous sampling is more recommended than instantaneous sampling. The establishment of a network monitoring the quality of rivers along the Congo River, however, will have sufficient data.

4. Conclusion

The study of the impacts of discharges on receiving watercourses using the models gives satisfactory results because they take into account both the quality of watercourses and discharges, and particularly the fact that river is actually taken a continuum. The model obtained in this study is adapted to simulate the fluctuations of dissolved oxygen as a function of the organic load. The point located at 3.9 Km reveals a severe and old pollution at this place (2.12 mg / L O_2 dissolved compared to the theoretical value found 4.97 mg / L O_2 dissolved). The low value of the Nash criterion shows that the Streeter-Phelps model, although satisfying in some respects, shows some weaknesses and needs improvement. This model constitutes for us a (basic) test model from which the physicochemical, ecological, biological and microbiological parameters influencing the oxygen balance in the watercourse will be progressively incorporated. This work is only the first step in the iterative process of constructing a quality model of a section of the Congo River because there is no universal model that can be applied indiscriminately, as Villeneuve would say .

References

[1] Hassan Partow, Problématique de l’Eau en République Démocratique du Congo, Défis et Opportunités, Rapport Technique, Programme des Nations Unies pour l’environnement(PNUE), Kenya, 2011

[2] Takoy Lomema. ’’Les ressources hydriques de la République Démocratique du Congo et les aspects connexes.’’ Actes du premier Colloque International sur la problématique de l’eau en R.D.Congo de

Kinshasa, Annales de la Faculté des Sciences, Presses de l'Université de Kinshasa, 2008, pp 51-59

[3] Yoann RAINAT, Implémentation du modèle de qualité des eaux QUAL2K sur le bassin versant de l'Arroux, M1 Sciences de l'Environnement, Université de Bourgogne ; 2015, pp 1-3.

[4] Céline Jacmain, Adaptabilité des contrats de Rivières au Bassin versant de la Lukaya en République Démocratique du Congo, TFE MC, Belgique, 2010 pp 2.

[5] Nada Nehme. Evaluation de la qualité du bassin inférieur de la rivière Litani, Liban, Approche environnementale (Thèse), Université de Lorraine ,2014 pp 1.

[6] Doulaye Kone, Epuration des eaux usées par Lagunage à microphytes et à macrophytes en Afrique de l'Ouest et Centre : Etat des lieux, performances épuratoires et critères de dimensionnement (Thèse), Ecole Polytechnique Fédérale de Lausanne, 2002 pp 2.

[7] Sikulisimwa Pole Céline, Diagnostic des biomasses épuratrices des stations d'épuration et des systèmes d'assainissement non collectif (ANC) (Thèse), Université de Liège, 2011, pp 12-14.

[8] Laure Pierron. Etat Chimique des rivières, Gazette Rivière n°26 ,2012 pp 1-4. cpie-val-de-gartempe@cpa-lathus.asso.fr

[9] Serge Hébert et Stéphane Légaré, Suivi de la qualité de l'eau des rivières et petits cours d'eau, Ministère de l'Environnement Gouvernement du Québec, Octobre 2000, pp 9-22.

[10] Sophie S. et al. Catalogue de modèles de qualité des cours d'eau, Revue des principaux outils de modélisation de la qualité des cours d'eau, Centre d'Etudes Techniques Maritimes Et Fluviales (CETMEF) ; France, 2010, pp 21- 43 / 71-72.

[11] Micheline Poirier et al. Lignes Directrices pour l'Utilisation des Objectifs environnementaux de Rejet relatifs aux rejets industriels dans le milieu aquatique, Canada, 2008, page 9-10 / 29-31.

[12] Dubin Ch. La mise en modèle mathématique de l'autoépuration des rivières, la Houille Blanche /N°8, 1971, pp 705-710. . Article published by SHF and available at http://www.shf-lhb.org or http://dx.doi.org/10.1051/lhb/1971047

[13] Thomas J.Grizzard. Deoxygenation – Reaeration and the Streeter-Phelps Equation, CEE 5134, 25 October 2007, pp 2-10/10-35

[14] Gotovtesev A. V., Modification of the Streeter Phelps System with the Aim to Account for the Feedback between Dissolved Oxygen Concentration and Organique Matter Oxidation Rate, Water resources Vol.37 N°2, pp. 245–251, Russie, 2010.

[15] J.N. Ugbebor, J.C. Agunwamba , V.E Amoh , Detrermination of reaeration coefficient K2 for pollued

stream as a function of de depth , hydraulic radius , temperature and velocity ; Nigerian Journal of Technology (NIJOTECH) , Vol 31 ,N° 2 July , 2012 , pp 174-180.

[16] Eckenfelder W.W, Gestion des eaux usées urbaines et industrielles ; Caractérisation-Techniques d'épuration-Aspects économiques, Technique et Documentation, Paris, 1982, pp 11-37, 38-70

[17] Stéphanie Laronde et Katell Petit, Bilan national des efforts de surveillance de la qualité des cours d'eau (Rapport final), Office national de l'eau et des milieux aquatiques (Onema) et Office Internationale de l'Eau (OIE), 2010 , pp 881-85.

[18] Jean Rodier Jean RODIER, Bernard LEGUBE, Nicole MERLET et coll. L'analyse de l'eau, 9ième édition entièrement mise à jour. Dunod, Paris ,2009 .

[19] Panaretos V.M., Davison A.C. et Kuonen. Probabilités et Statistique pour Sciences de l'Environnement ; Ecole Polytechnique Fédérale de Lausanne, 2013 , pp 74-78.

[20] Bardel C. La corrélation : Présentation et test du coefficient de corrélation de Pearson .Master 2 Neurosciences, Septembre 2016 pp 1-30 ; Source : http://xkcd.com/552

[21] Jacques Nicolas, Outils et statistiques et mathématiques pour le traitement des données environnementales, Surveillance de l'Environnement, ULG, page 123-159, 2005.

[22] Ricco Rakotomalala. Analyse de corrélation, Etude des dépendances-Variables quantitatives, version1.1. Université Lumière Lyon 2, 2017, pp 3-17. http://dis.univ-lyon2.fr/

[23] Edeline F. Pouvoir auto épuratoire des rivières, Une introduction critique. Cebedoc, Paris 2001, pp 180 -200.

[24] Ellis, T.G. ; D.S. Barbeau ; B.F. Smets et C.P.J. Grady, Détermination des paramètres cinétiques décrivant la biodégradation par respirométrie, Recherche environnementale en eau 68(5) pp 917-926.1996.

[25] Cluis D. Analyse des réactions en rivière : Modèles mathématiques de qualité, Revue de littérature, Rapport scientifique n°23, Institut National de la Recherche Scientifique (INRS)-Eau, Université du Québec ,1973 pp : 3-4 / 22-40.

[26] Daniel Maurer, Modélisation de la dispersion des effluents rejetés au wharf de la Salie, Agence de l'Eau 1997 pp 1-2.

[27] Kabele Ngiefu C. et Munginda Yong F. Pollution et degré d'auto-épuration des rivières de Kinshasa Actes du premier colloque international sur la problématique de l'eau en République Démocratique du Congo (RDC), 2008 pp 156-174.

[28] Lefort D., Modèles mathématiques de pollution de rivière, Centre de Recherche de Pont-à-Mousson, la Houille Blanche N°8, 1971, pp 669-704.

[29] Pierre-Alain Roche, Jacques Miquel, Eric Gaume ; Hydrologie quantitative, Processus modèles et aide à la décision ; Springer Verlag France, 2012 pp 242-244.

[30] Liechti Paul, Méthodes d'analyse et d'appréciation des cours d'eau. Analyses physico-chimiques, nutriments. L'environnement pratique n°1005. Office fédéral de l'environnement, Berne. 44 p. 2010 pp 11-36. ;

[31] Jérôme Dispan, Biodégradabilité de la matière organique dans le continuum aquatique, réseau d'assainissement-station d'épuration-milieu naturel récepteur (Thèse), Ecole National des ponts et chaussées, 2003, pp 29-36.

[32] Villeneuve J.P., Hubert P., Mailhot A. et Rousseau A.N. La modélisation hydrologique et la gestion de l'eau. Journal des Sciences de l'Eau, Vol 11, 1998, pp19- 39

URL id.erudit.org/iderudit/705327ar Document generated on 10/24/2017 6:34 a.m.

[33] Figuet C. et Frangi J.P. Les cours d'eau réceptrice de rejets de stations d'épuration : le cas de la Mauldre (Ile-de-France), un milieu sous très haute pression. Revue des Sciences de l'Eau 13(2) ; 2000 pp 119-138.

[34] Tangou Tabou Thierry, Etude et modélisation de la contribution des macrophytes flottants (Lemna minor) dans le fonctionnement des Lagunes naturelles (Thèses), Université de Liège 2014 pp 2 : pp 91.