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RESEARCH ARTICLE

STUDY OF THE HYDROMETRIC SIGNATURE AND IMPLICATION OF SPRING TIDE CONDITIONS IN THE WOURI-NKAM CHANNEL OF THE CAMEROON ESTUARY

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ABSTRACT

The upper channel of the Wouri-Nkam section of the Cameroon estuary is poorly studied due to the limited finance, difficulties in accessibility, lack of political interests and information about its crucial role in the welfare of the local population. This study assessed short term fluctuations of hydrometric parameters to characterize the hydro-ecological system of this channel. High-frequency sampling of water level, surface currents and water quality parameters (Temperature, Salinity, pH, dissolved oxygen etc) were conducted during two spring tide conditions (May 2019 and 2020). The results obtained after spatial and statistical analysis revealed that salinity displayed a horizontal gradient ranging from the Bridge to Bona'Anja, with the first zero salinity (0 PSU) around Bonalokan (7 km away from the Bridge). The hydro-ecological status revealed a hypoxia situation (Dissolved oxygen concentration less than 2mg/l) in May 2020. Also, the two boundaries of this channel exhibited different current directions with amplitudes of about 1.2 m/s in the Bridge (with bidirectional flow and more important small scale features) and 0.23m/s in Bona'Anja (unidirectional flow). Similarly, the tidal range losses about 74% of its amplitude as it travels from the Bridge to Bona'Anja (May 2020). The correlation coefficients (r=0.71) obtained between water level and water quality parameters (salinity, conductivity and Total Dissolved solutes (TDS) confirmed the synchronized evolution observed between them with a time lag of about 1hour.

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INTRODUCTION

Estuaries are coastal areas where freshwater is mixed with seawater (Pritchard,1967).Rivers and estuarine systems around the world are affected by changes in land use, hydrological and biogeochemical cycles mainly driven by the continuous increase in population (Neal, 2004; Boyer *et al.,* 2010; Sabater and Stevenson, 2010).In coastal countries, especially in the developing world, cities located along the coast are exposed to intense industrialisation, rapid population growth and consequently huge human activities (Fantong *et al.,* 2016).

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These activities affect the quality and quantity of water resources in shallow estuarine systems. The Biological (mangrove stand, species distribution, nursery grounds etc.,), geomorphological (bathymetry and the sizes of the estuary) and hydrological (water movement, distribution and quality) components of such estuarine systems have changed drastically due to rapid population growth in the neighbouring neighbourhoods. Furthermore, climate change that could cause increases in temperature and salinity of estuarine waters (Savoye*et al.,* 2009), with a direct influence on behaviour and distribution of zooplankton communities (David *et al.,* 2005) are becoming more intense. Land uses and climate variations, in combination with the geomorphological component of an estuary, are the ultimate determinants of hydrometrical behaviour (change in a continuous flow, water level and water quality) of an estuarine system. The amplitude of change especially during a spring tide period is a good indication of the dynamics in the hydrological parameters that can explain the migratory pattern of fishes, sediments dynamics and water volumes exchanged. For this reason, the description of these parameters as well as their inter-annual, seasonal, lunar regime and small tidal scale variations are essential in the understanding of the aquatic biota dynamic. However, forecasting the answer of the estuarine system to global and/or local changes which is of paramount important in the management and maintenance of good water quality and ecosystem functioning (Sabaterand Stevenson,2010) remains a scientific challenge in the developing world. The time-series monitoring of aquatic system that has been recognized long ago to better understand short and the long-term changes (Neal, 2004; Baborowski *et al.,* 2004; Blain *et al.,* 2004; Horowitz, 2009) are still scared. In the absence of historical detailed dataset, it is difficult to determine the dynamic of the hydrological parameter in such estuaries.

In the Cameroon estuary, The continuous depletion and deterioration of water quality haveplayed an important role not only in reducing the biodiversity and hence services of the estuary's ecosystems but also, the shrinking of the river banks, degradation of fishing grounds and loss of drinking water supply. Also, the quasi annual flooding event occurring in the upper Wouri-Nkam channel have increases awareness in the scientific community to investigateon the mitigation and the various socio-economic impacts of these hazards. Furthermore, the vulnerability related to climate change, especially sea-level rise, is amplifiedby the high level of anthropogenic pressure on the Wouri estuary (Ellison and Zouh, 2012). These impacts are (i) the increase in frequency and duration of the tidal inundation that may cause the death of the mangrove trees, reduce the quality of water supply and hence change the structure of fisheries populations (Ball, 1988), (ii) the inland freshwater marinization and contaminants disposal in the intertidal systems (Woodroffe *et al.,* 2016), and (iii) the change in the topography and hydrology due to change in sediment distribution (Lovelock *et al.,* 2015). This situation will surely affect the well-being of the local population and has consequently increase questioning about the hydrological and hydrometric status of the Wouri estuary, especially in it Wouri-Nkam section that is connected to the various neighbourhoods (Nfotabong-Atheull *et al.,* 2011). Furthermore, the temporal variation of water levels, dynamic of water qualityparameters and flow rates characteristics that typically takes place at two distinct time-scales; long term (inter-annual and seasonal variability) and short term (e.g., daily, semi-daily and/or hourly fluctuations)is still hampered by lack of data. The short-term fluctuations (daily, half daily and hourly) are rarely discussed intextbooks (Gribovszki *et al.,2010*). However, The few existing studies in this area are focus onthe water quality(Fantong *et al.,* 2016), physical and chemical characterization (Togue *et al., 2017*), hydrological regime Olivry (1974), level dynamic in the lower estuary(Onguene*et al.,2014*) and small sales dynamics of tidal prisms (Besack *et al.,*2020). These studies were carried out at different scales and have not combined other parameters to investigate the global status of the hydrological parameters.Also, the spring tide conditions that carry bedforms and materials in and out of estuaries limits have not yet received any particular attention.

There isa concluding desire of studying and understanding the dynamics of the various hydrometric parameters in the Cameroon estuary with specific attention in the Wouri-Nkamchannelwith the aim of developing a sustainable management program (tool) that require the understanding of the functioning of this environment at different time scales. This paper has focused on the analysis of changes in small scale features (1hour) of surface current flow, water level and water quality during spring tide conditions without rainfall influence. Such a high-frequency time-series would permit to examine questions about the role of the tide (semi-diurnal cycle) on the hydrological signature of the water in the Wouri-Nkam channel of the Cameroon estuary.

METHODOLOGY

Presentation of the study ground / Site description: In Cameroon, the Wouri Estuary (8250km^2) is one of the largest in terms of surface area and mean annual discharges in the Gulf of Guinea. It has attracted more than 3millions inhabitants in its vicinity making the city of Douala the most populated. This city bears 75% of the industrial fraction and produces about 31.2% of the total national income. Its upper section is connected to about 70% of the total population of the city of Douala and this imposes a high demand of freshwater supply for domestic, industrial and agricultural uses that has consequently increase the pressure on this resource. This depletion is exacerbated by the poor policy in term of sand sediments mining, fishing activities and mangrove forest destruction. From a geographical point of view, this estuary is located between latitude 04°01' and 04°06'north and longitudes 09°40' and 04°40' 09°45' East (Figure 1A and B). The Wouri estuary is a partially mixed to well-mixed macro-tidal estuary with tidal amplitudes ranging from 2 to 2.5 m at the mouth. The depth ranges between 01.5 and 6 m in the upper estuary and can reach up to 25 m in the lower estuary. The tidal wave propagates more than 60 km upstream from the mouth (Olivry, 1974). This estuary system is said to be hypersynchronous (Besack *et al.,* 2020); the tidal amplitude increases progressively towards the upper estuary, reaching its maximum value at 30 km away from the mouth before decaying in the fluvial narrow sections. Therivers that flow in the upper channel of the Wouri estuary are the Mbanya, Tongo Bassa, Mboppi and the Ngongué(Figure 1C). Furthermore, during high tides, the Dibamba and Wouri rivers that flow into the ocean are vulnerable to bank overflow and seawater intrusion; while at low tides, the upstream channels of those rivers run dry.The upper channel saving as a junction between the brackish and freshwater (Figure 1C and D) bears neighbourhoods such as Bonaberi, Deido, Akwa Nord, Besseke, Denver, Bangué, Yassem, Bossamba, Bonepea etc., (Figure 1D) exerting high pressure that constitute an important source of human pollution and shrinking of the Wouri estuary.

Data collection

Selection of sampling stations: Before the local cruises, maps of the Cameroon estuary were used to select the different sampling stations. Eleven (11) sampling stations were selected along the upper section of the estuary for the monitoring of surface currents and water quality parameters. The water level was measured at the two boundaries (upper and lower) of the study ground. The distribution of these stations took into account the land/site occupation, population density, spatial heterogeneities due to natural or anthropogenic effluents and population activities (Figure 1) as presented in Table 1. The overall criteria used in the selection of the various sampling stations are presented in Table 1 below.

The different locations are given as kilometre points (KP) which correspond to the distance from the mouth of the estuary.

Field measurements: The field measurements took place in May for the year 2019 (17-18/05/2019) and 2020 (08-09/05/2020), precisely during spring tides conditions with tidal coefficients ranging between 95 and 110 (https://tides4fishing.com). These periods were chosen because it is rainless and present an average river flow of 140m3/s, value laying between the minimum and the maximum discharge of 65m3/s (February) and 340m3/s (November) respectively (Olivry,1974). The local cruises concerned in this study included morpho-bathymetric survey, spatial and temporal measurements of surface currents and water quality parameters (salinity, temperature, dissolved oxygen (DO), pH). Water level data were continuously collected in the lower Bridge and the upper Bona'Anja sections by the Douala Harbour Authorities (PAD) and the Center of Tropical Aquaculture (CAT) respectively.

Morphometric, Surface current velocity and water quality parameters

These sets of parameters were monitored from the Bridge to Bona'Anja Siga Bonjo (28km away from the Bridge station). A total of 11 (eleven) sampling stations (transects) were selected within this area (Figure 1). The displacement from one point to other within the channel was done using a flying-boat (40 horse feets). The parameters concerned here were monitored during both Flood and Ebb tides conditions of each spring tide regime. During the morphometric surveys, the distances separating the various banks were given by a GPS and/or a measuring tape depending on the width size. The surface currents velocities were monitored using a drifter, five (05) cross-sectional elementary measurements covering the channel's width were conducted in each transect. The mean or mode values were recorded. Similarly, the water depths were given by the monobeam fish finder stricker of brand Garmin, with incorporated GPS. At the same time, water quality parameters (salinity, conductivity, total dissolved solutes (TDS), Dissolved oxygen (DO), temperature and pH) were censored using the multi-parameter data-sonde of brand HANNA. These measurements were conducted in all the eleven sampling station during flood and ebb tide conditions.

Besides the above spatial measurements, time-series measurements of water quality parameters were continuously sampled at the two limits station (Bridge and Bona'Anja). The water quality parameters were synchronously collected between these stations for atleast half a day (12h30mins) with a time step of 30mins. The aim was to understand the high frequency change that occurs in surface currents, water level and water quality parameters within minutes/hour time scales as shown by Tomlinson and De Carlo (2003).Furthermore, raw water samples were collected at these points and returned to the laboratory for calibration and validation of the in situ measurements (Salinity, Conductivity, TDS, pH and DO) observed with the multiple parameters.

Tidal Data: The water level in the Bridge was provided by PAD while that of Bona'Anja was provided by the CAT. These two hydrometric stations PAD (Radar sensor type) and Bona'Anja (pressure sensor type) were calibrated for times steps samplings of 10 minutes and 1hour respectively.

Data processing and Analysis

Pre-processing data such as discharge rate and saline mixture were computed before statistical analysis. The discharge rate was obtained by multiplying the mean velocity by the cross-section area of water (Equation 1).

$$Q = U \quad L \quad D \qquad (1)$$

Where U, L and D symbolize the water velocity, estuary width and depth respectively. The mixing of fresh-brackish water was expressed as a percentage contribution and was given by Equation 2

$$M = {}^{Sobs}/_{Sb} \times 100 \qquad (2)$$

Where M, Sobs and Sb are the brackish water contribution, observed salinity and the mean salinity of the middle estuary during spring conditions of May. All the Data were arranged to reveal the relationship between temporal variations of water elevation and the other hydrological parameters (salinity, temperature, conductivity, dissolved oxygen and pH). The statistical analyses were performed using Matlab software, 2013 version. The Pearson correlation analyses werecarried out to determine the significant correlation between hydrological variables. Spatial correlations were also performed to determine statistical significant correlations between the studied parameters controlling the study site as shown by Bai *et al.,* 2010. The results for the physical and chemical analysis, mentioned above, are also represented by mean ± standard deviation.

RESULTS

The spatial evolution, time-series dynamics and the effect of spring tide on the hydrometric variables were explored. The results obtained are presented in this section and grouped as spatial, temporal and correlations observed.

Longitudinal signature of the monitored water quality parameters: Daily snapshot of the spatial distribution of the monitored water quality parameters, for May 2020 (because of it greater coverage) survey are presented in this section (Figure 2). The results obtained show that; The spatial distribution of Dissolved oxygen (DO) revealed a poorly oxygenated channel (DO < 2mg/l). This oxygen depletion implies that this section of the estuary was in a hypoxia condition during the spring tide of May 2020. This result also showed that Floodtide has a relatively higher DO concentration compared to its successive Ebb tide. The horizontal DO gradient observed during flood tide was not noticed during the following Ebb condition i.e., the maximum and minimum DO concentrations were recorded in Yassem (1.6mg/l) and Ngombe (1.1mg/l) respectively.

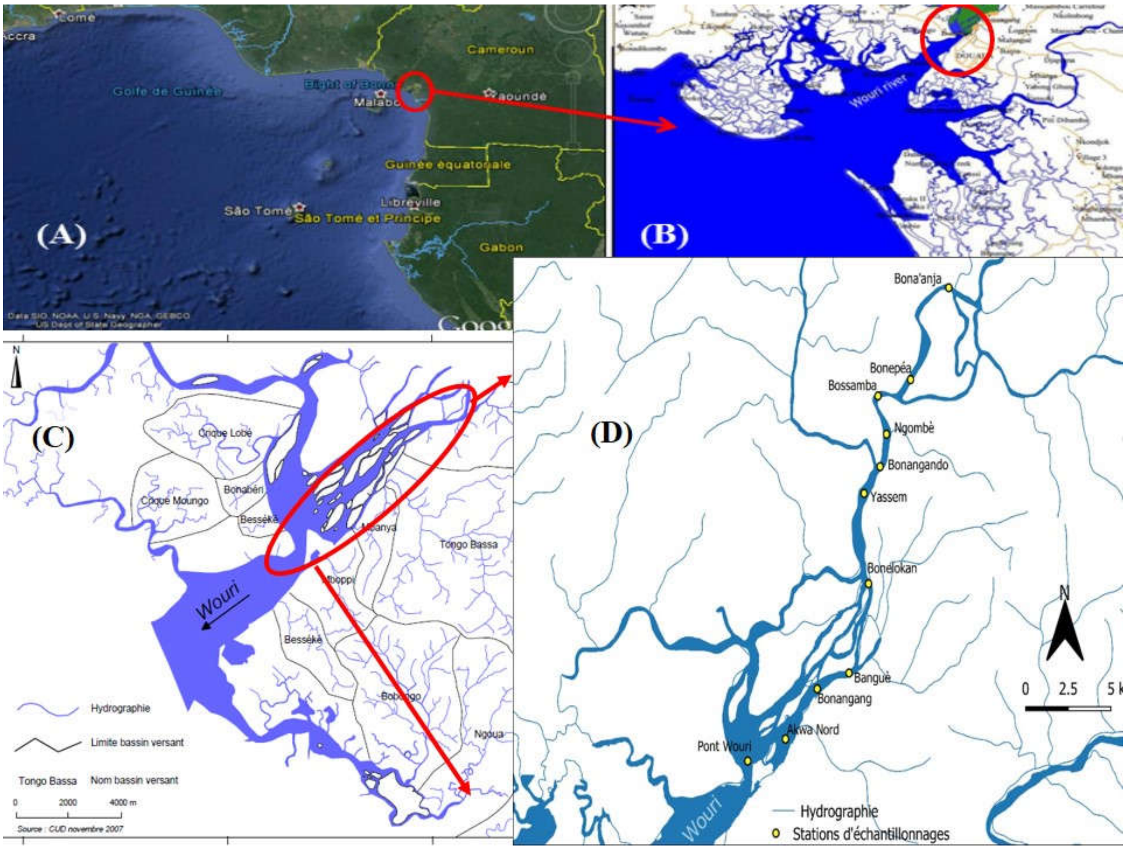

Figure 1. Location of the Wouri-Nkam section of the Cameroon Estuary (A andB) showing the Wouri-Nkam channel (C) and the various sampling station and the corresponding neighbourhoods of the city of Douala (D)

Table 1. Presentation of the selected sampling stations

Point Name	Latitude	Longitude	Name kilometric (KM)point distance from the mouth (Km)	Descriptive characteristics
Bridge	4.073108	9.696038	KP 27	Presence of Cement industries, Mangroves stands and housing facilities.
Akwa Nord	4,077512	9,714731	KP 28	Housing, fishing land and sediments market
Bonagang	4,085502	9,719025	KP 30.510	Sediments market, housing facilities
Bangue	4.110945	9.74996833	KP 31	Housing, sands extraction and market
Bonalokan	4.14722167	9.75700333	KP 35.225	Sediments extraction site and mangrove stand
Yasem	4.18522167	9.75408833	KP 39.311	Fishing village
Bonagando	4.19314333	9.763125	KP 43.51	Fishing village
Ngombe	4.20818833	9.76855833	KP 44.836	Fishing village
Bossama	4.22473667	9.76159833	KP 46.605	Fishing village
Bonapea	4.2313433	9.77869167	KP 50.62	Fishing village
Bonaanja	4.26832667	9.80019333	KP 55.356	Agricultural, sands exploitation activities and Tourism development

Table 2. Trends in monitored parameters in Wouri bridge (comparing May 2019 and May 2020)

May 2019					
	maximum	minimum	range	mean	STD
Temperature (°C)	32.09	29.26	2.83	30.35	0.78
Dissolved Oxygen (mg/l)	10.72	4.99	5.73	7.67	2.12
Salinity (PSU)	4.7	0.1	4.6	1.2636	1.4787
Conductivity (uS/Cm)	8.75	0.228	8.522	2.4307	2.7421
TDS (mg/l)	5.41	0.147	5.263	1.5227	1.7036
pH	9.5	6.54	2.96	8.5309	0.8296
Orthophosphate (mV)	267	33	234	180.8182	59.8044
Turbidity ( )	1000	85.8	914.2	253.9818	256.6385
May 2020					
Temperature	30.89	26.08	4.81	29.47	1.26
Dissolved Oxygen	2.03	1.22	0.81	1.45	0.20
Salinity	6.74	0.01	6.73	1.06	1.50
Conductivity	7.69	0.01	7.68	1.97	2.77
TDS	3843	05	3838	1008	1372
pH	7.24	6.90	0.34	7.05	0.10
Orthophosphate	208.10	78.90	129.20	127.89	44.93
Resistivity	91000	130	90870	9468	1854

Table 3. Descriptive statistic of monitored parameters in Wouri Bridge

Bridge					
Parameter	maximum	minimum	range	mean	STD
Temperature	30.89	26.08	4.81	29.47	1.26
Dissolved Oxygen	2.03	1.22	0.81	1.45	0.20
Salinity	4.21	0.01	4.20	1.06	1.50
Conductivity	7.69	0.01	7.68	1.97	2.77
TDS	3843	05	3838	1008	1372
pH	7.24	6.90	0.34	7.05	0.10
Orthophosphate	208.10	78.90	129.20	127.89	44.93
Resistivity	91000	130	90870	9468	1854
Bona'Anja Siga Bonjo					
Temperature	29.96	28.67	1.29	29.43	0.31
Dissolved Oxygen	1.32	1.14	0.18	1.10	0.12
Salinity	0.00	00.00	0.00	0.00	0.00
Conductivity	0.07	0.04	0.03	0.06	0.01
TDS	54	29	25	34.00	6.86
pH	7.11	7.01	0.93	7.03	0.4
Orthophosphate	223.60	168	55.60	195	26
Resistivity	18840	14930	3910	16032	1021.6

Table 4: Pearson correlation coefficients between tide/river discharges and monitored physical/chemical parameters in the Wouri bridge and Bona'Anja (May 2020)

WOURI BRIDGE			*BONAANJA SIGA BONJO*	
parameter	*Water level*	*River discharge*	*Water level*	*River discharge*
Sal	0.71	-0.86	0	0
TDS	0.71	-0.91	0.34	0.55
COND	0.71	-0.90	-0.03	0.40
OD	0.43	0.72	-0.48	0.53
PH	-0.24	-0.91	0.20	-0.34
TEMP	-0.01	-0.93	-0.29	-0.63
ORP	-0.17	0.94	0.07	-0.74
RESIST	0.31	0.55	-0.17	0.35

Table 5. Pearson correlation between monitored parameters in the Bonaberi Bridge (combined 2019 and 2020 datasets)

	Sal	*TDS*	*Cond*	*OD*	*pH*	*Temp*	*ORP*	*Resist*
Sal	1							
TDS	0.99	1						
Cond	0.99	0.99	1					
OD	-0.53	-0.52	-0.55	1				
pH	-0.01	-0.02	-0.01	-0.25	1			
Temp	0.34	0.35	0.34	0.09	-0.34	1		
ORP	0.84	0.83	0.84	-0.49	-0.16	0.28	1	
Resist	-0.32	-0.37	-0.36	0.24	-0.05	-0.18	-0.08	1

Table 6: Pearson correlation between monitored parameters in Bonaanja siga bonjo (combined 2019 and 2020 datasets)

	Sal	*TDS*	*Cond*	*OD*	*pH*	*Temp*	*ORP*	*Resist*
Sal	1							
TDS	0	1						
Cond	0	0.34	1					
OD	0	-0.08	0.11	1				
pH	0	0.06	-0.21	-0.42	1			
Temp	0	0.41	0.30	0.27	-0.10	1		
ORP	0	-0.09	-0.23	-0.40	0.66	0.05	1	
Resist	0	-0.88	-0.42	0.04	0.06	-0.53	0.13	1

Similarly to DO, Salinity presented relatively higher values during flood tide than its consecutive ebb condition. Salinityalso displayed a decreasing horizontal gradient during both tidal conditions. While the flood tide gradient ranged from the Bridge to Bona'Anja, with a first 0 PSU around Bonalokan (km35.31; i.e., 07km from the Bridge) indicating the limit of the tidal excursion (Oligo-haline) (Figure 2), the ebb gradient has it limit just around Bangue.The maximum salinity values in the lower transects representing the flood tide were 6.74, 2.9, 0.9, 0.5 and 0.3psu for the Bridge (km28), Akwa Nord (km29), Bonangang (km30), Bangue(km31), Bonalokan (km35.23) respectively. Similarly, during ebb tide, these values dropped to 2.31, 0.24, 0.19 and 0.00 PSU respectively for Bridge, Akwa Nord, Bonangang and Bangue. Looking at the Temperature, the results obtained showed that surface water temperaturewas relatively higher during ebb compared to flood tide (except in Bossamba). The longitudinal ebb evolution ofsurface water temperature varied between 30.89 to 26°C and between 26.99 to 29 °C during the following ebb tide. This indicates that the water was warm throughout the sampling period. During ebb tide, the Bridge was the warmest segment while the lowest temperature value was registered in Bossamba (26°C), this trend was changed

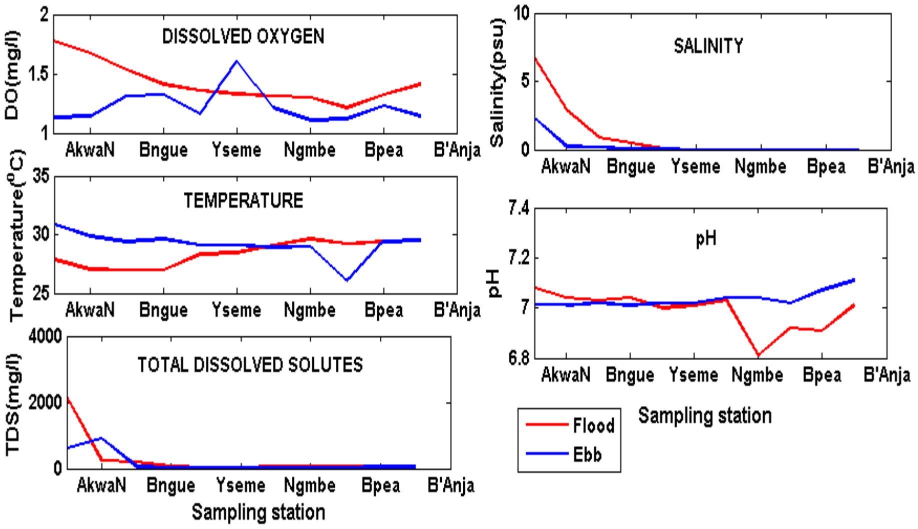

Figure 2. Spatial evolution of physical and chemical parameters, a) Temperature, b) DO, c) Salinity and pH) in the 2020 survey

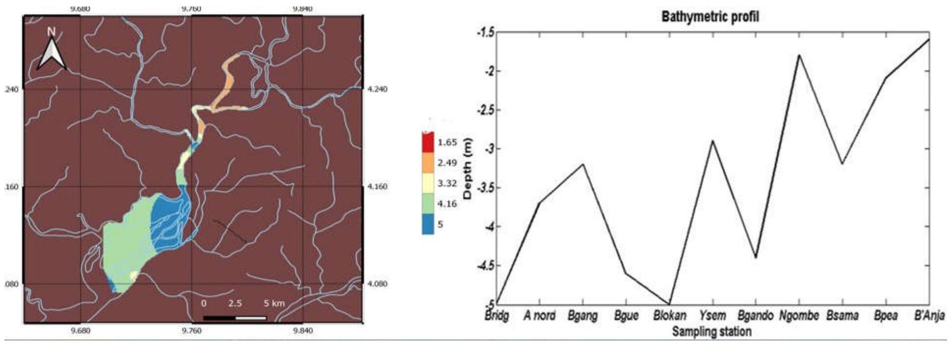

Figure 3: Evolution of depth in the upper section of the Cameroon estuary

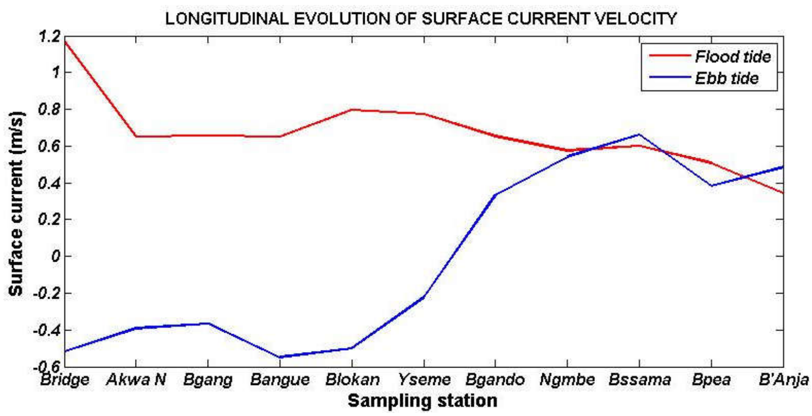

Figure 4: Surface current evolution along the Wouri-Nkam section of the Cameroon estuary

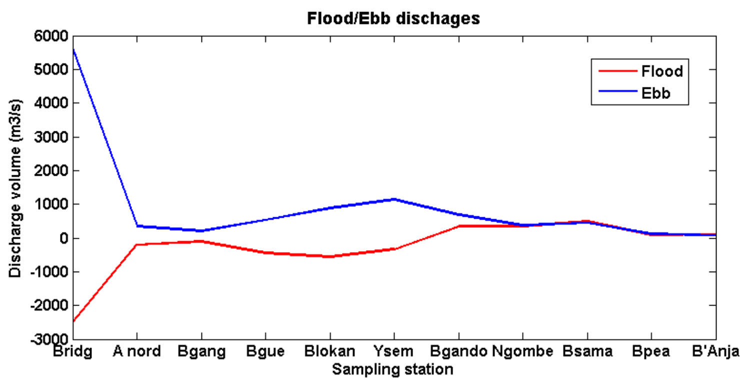

Figure 5. Spatial distribution of discharge flows during Flood and Ebbtide
The negative values represent a reverse current (red line of flood tide)

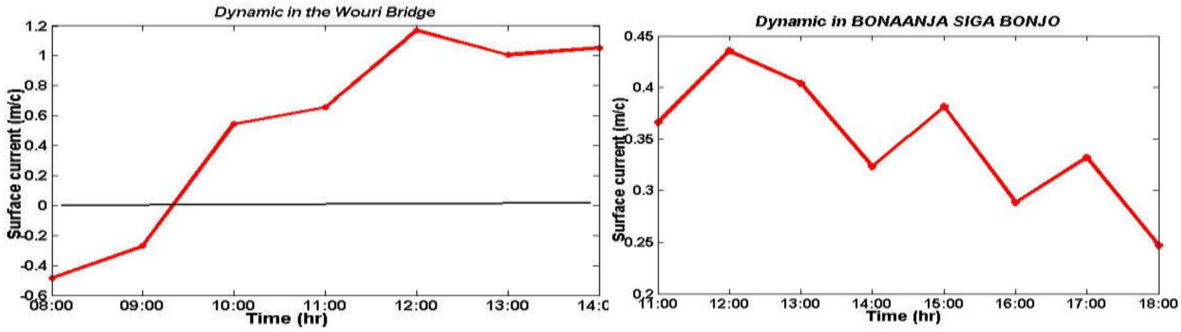

Figure 6: Surface currents temporal dynamic in the Bridge and Bonaanja Siga Bonjo

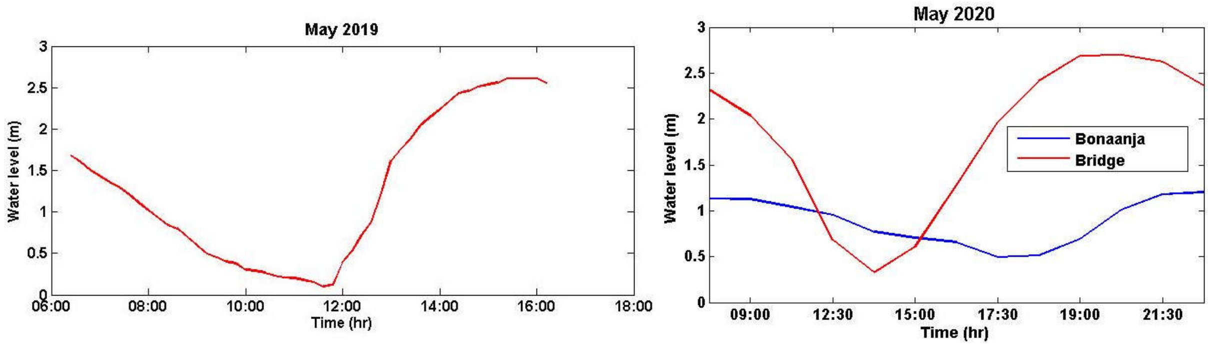

Figure 7: Water level evolution in the Bridge and Bona'Anja during May 2019 (A) and May 2020 (B)

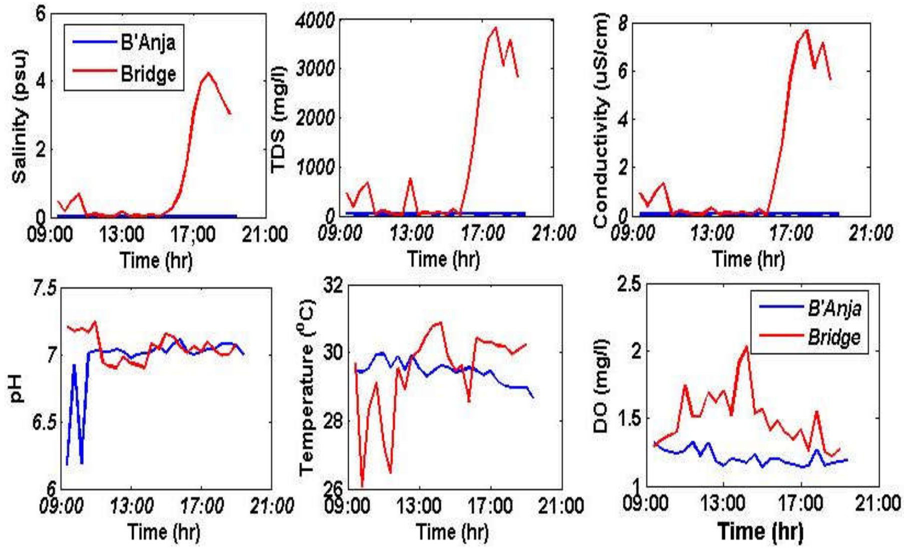

Figure 8. Evolution of water quality parameters in the Bridge during the May 2020 local cruise Red lines for the Bridge and blue lines representing Bona'Anja

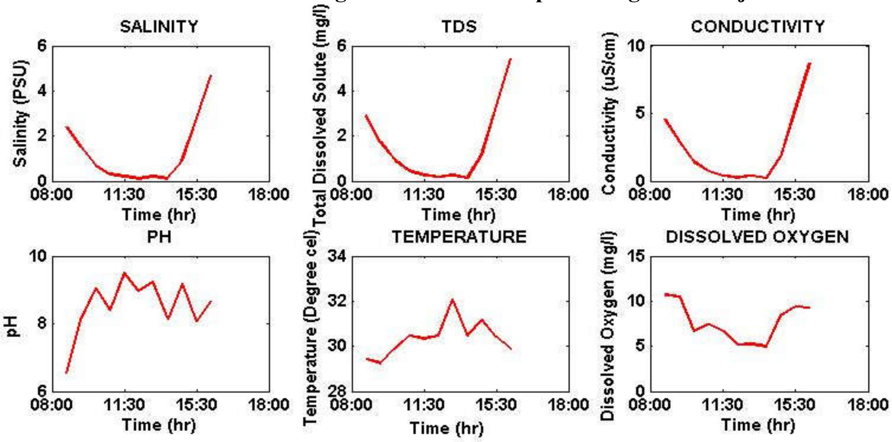

Figure 9. Evolution of water quality parameters in the Bridge during the May 2019 local cruise Bona'Anja data were absent during this period

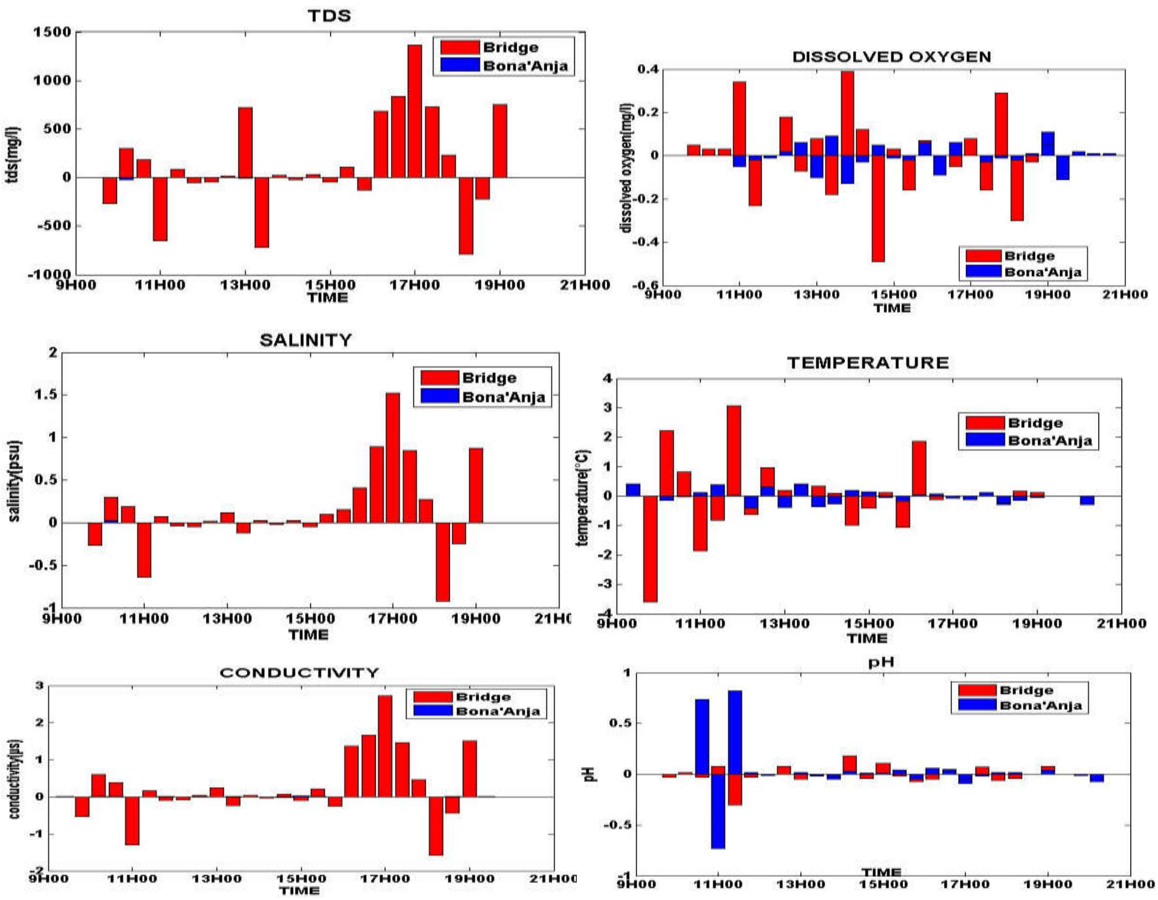

Figure 10. Small scales dynamics of water quality parameters in the Bridge section.

during flood tide with the warmest point at Bona'Anja (29.5°C) and the coldest in Bangue (26.99°C). Concerning pH, we noticed that the water was relatively neutral (pH values near 7), with a small range of variation (7.01 to 7.11) during both tidal conditions (with the small change from Ngombe to Bona'Anja). We also observed from this result that, during flood conditions, the pH value fall from Ngombe (6.8) upward to Bona'Anja and remain relatively lower compared to the values observed in the lower channel. The Total Dissolved Solutes (TDS) was very low from Bangue to Bona'Anja during both tidal conditions. Despite the higher value observed in the Bridge during the flood, no clear conclusion can be made about the domination of flood or ebb when regarding this variable.

Springtide dynamics of monitored water quality parameters: Short-term changes in water quality parameters (Salinity, DO, Temperature and pH) during rainless periods is a phenomenon relatively rarely investigated throughout the world. Five statistical indicators (maximum, minimum, range and standard deviation) were employed to obtain the general information of the hydrometrical status of the Bridge (due to itsposition as channel's entrance and it tidal influence) at this scale. Table 2 compare these statistical indicators as a function of physical and chemical parameters in the Bridge station between the two local cruises (May2020 and May 2020). The standard deviation (std) values of DO highlight that the spring tide in May 2019 was more dynamic (table 2).The maximum/mean values in the Bridge were 10/7.67 ±2.12 mg/l for 2019 and 2.3/1.45± 0.20 mg/l in 2020 respectively. This value implies that this section of the estuary has a good oxygen content in 2019 and a hypoxia condition in 2020.

During the spring tide of May 2020, the thermal range remained was 4.83°C (30.89-26.08°C ±1.26). This temperature range reduces to 2.83°C in 2019 revealing an inter-spring dynamic in temperatures (Table 2). These results also concluded that the year 2019 was warmer with Maximum/median temperature values of 32.09/30.35±0.78°C while 2020 has maximum/median values of 30.89/29.47±1.26°C. In term of temperature, 2020 was found to be more fluctuating when regarding their std values. Salinity is one of the most important variables related to water quality that contributed to the formation of brackish water that changes the composition of estuarine physical and chemical parameters and hence species distribution. The inter-spring comparison showed that the maximum/mean salinity in the Bridge segment changes from 4.7/1.3±1.47PSU in 2019 to 6.74/1.06 ±1.5psu in 2020. However, their std values of 1.48 and 1.5PSU for 2019 and 2020 respectively does not show any significant difference in spring conditions between these cruises. The hydrogen ions concentration is a good proxy of Dissolved Inorganic Carbon (DIC) in water. Table 2 of the water quality hydrometrywithin the two spring tidal regimes showed that the spring tide condition of the year 2019 showed a more basic character with maximum/mean values of 9.5/6.54±0.83compared to 7.24/7.05 ±0.10 of 2020, this suggests a more stable 2020 and a more vibrating 2019. This dynamic could also be confirmed from their STD values of 0.83 (2019) and 0.10 (2020).

Fixed stations comparison in monitored parameters (Bridge and Bona'Anja 2020): These two points were selected because they represent the lower (Bridge) and upper (Bona'Anja) ends of the studied channel.

The aim of this monitoring focused on depicting the daily changeof water quality parameters within the two limits of the channel. Again only the spring tide of May 2020 local cruise was chosen and this was due to better coverage (more data coverage). Also, the maximum, minimum, range, median and standard deviation values were associated to clearly distinguish the daily dynamic between these two segments. The results of this descriptive statistic are presented in table 3 below, they showed that, with exceptions ofOrthophosphates ions (ORP) and DO, the greater range were recorded in the Bridge segment. The range values of temperature (4.81°C), Dissolved oxygen (0.81mg/l), Salinity (4.20PSU), Conductivity (7.68 uS/cm), TDS (3838mg/l) and Orthophosphate ions (129.20) were greater in the Bridge (table 3) compared to their corresponding values in Bona'Anja (table 3). This means that the Bridge segment was more dynamic than of Bona'Anja during the spring tide conditions of May 2020. Their corresponding std values confirmed this distinction i.e., the Bridge portion (higher STD) was more dynamic compared to Bona'Anja (relatively lower STD). Looking at the daily mean (table 3) snapshot of water parameters, we noticed that, the Bridge has higher mean values in term of temperature (29.47±1.6°C), DO (1.45±0.20mg/l), salinity (1.06±1.5psu), conductivity (1.97±2.77), TDS (1008±1372), pH (7.05±0.10).

Longitudinal signature of the Hydro-morphological parameters (Surface current velocity, discharge flowand the bathymetric profile): These parameters represent an integral component of the processes influencing estuarine configurations and functioning (Roy *et al.,* 2001; Powel *et al.,*2002; Estevez, 2002). They may have an overwhelming effect on the composition, abundance, productivity and distribution ofaquatic biota. In this section, only the surface current measurements of the spring conditions in May 2020 were considered (Figure 4). The positive values represent the outgoing direction (ebb tide current) while the negative values illustrate a tidal induce incoming direction (flood condition).

The outcome of this spatial assessmentrevealed a bidirectional current velocity from the Bridge to Ngombe (20km from the Bridge; i.e., 47km from the mouth). While this surface currents remain unidirectional (blue line, Figure 4) in the remaining part of the channel (i.e., from Bossamba to Bona'Anja) during both tidal cycles of the spring condition of May 2020. Also, during flood condition, the volume of brackish water that passes through the Bridge (KP 27) to enter the Wouri-Nkam channel of the Cameroon estuary was about 2500m3/s (red line, Figure 5). Inversely, the volume ofwater leaving this channel during Ebb tide was 5000m3/s (blue line, Figure 5). These values progressively reduced upstream to Bona'Anja with a constant flow at from Ngombe. On the bathymetry survey (Figure 3)illustrated that the depth profile showed a general decreasing trend from the Bridge to Bona'Anja, with very pronounces spatial fluctuations of raise and fall in-depth (Figure 3A and B). The deepest segments were the Bridge (-5m)> Bangue (-4.6m)> Bonangang (-4.4m) while the shallow ones were Bona'Anja (-1.6m) > Ngombe (-1.8m) > Bonapea (-2.1m).

Temporal signature of surface current dynamics in the Bridge and Bona'Anja Siga Bonjo (~~Limits~~ Boundaries stations): The time series curves obtained from the surface current analysis detected sub-daily temporal change of the surface currents velocity in the two limits of the studied channel (Figure 6). The results obtained revealed that the Bridge have more pronounced sub-daily dynamic. Looking at the spatial scale, the Bridge (1.2m/s) has greater currents intensities compared to Bona'Anja (0.2m/s) representing an axial current loss of about 83.3%. The minimum values alongside these maximums were 0m/s and 0.2m/s registered respectively in the Bridge and Bona'Anja confirming that the Bridge is more dynamic. The 0m/s observed in the bridge at 09:30 corresponds to the high water slake. Looking at the temporal fluctuation, we noticed that, apart from the decreasing trend in Bona'Anja (Figure 6), the surface current remains positive (downstream direction) throughout the day, with the maximum around noon and a minimum around 6:00pm. On the other hand, the Bridge with a generally increasing pattern showed its minimum value (0.0m/s) at 09: 30 am and the maximum of 1.2m/s around noon. This implies that the Bridge exhibited a typical directional current with inversion around 09:45am (Figure 6), with maximum values of -0.6m/s and 1.2m/s during incoming (flood tide) and outgoing flows (Ebb tide) respectively.

Semi-diurnal signature of Water level: Two fixed hydrometric stations were installed in the Bridge and Bona'Anja, separated from each other by about 30km. The time series curves obtained after analysis (Figure 7) confirmed that, around the Bridge, the tide is semi-diurnal and the channel is meso-tidal in the description; the amplitude of elevation was 2.7 in 2019 (red line, Figure 7) and reduced to 2.3m in 2020 (red line Figure 7). This highlight the existinginter-spring tidedynamic with the spring tide of May 2019 being more extreme compared to that of the year 2020. The analysis ofFigure 7 also revealed a tidal distortion as the tidal wave penetrates the estuary; the tidal range changes from 2.3m in the Bridge to 0.6m around Bona'Anja (blue line, Figure 7). This reduction represents about 74% ofthe amplitude observed in the Bridge. Also, the tidal wave takes about 5hours to travel the 30km from the Bridge to Bona'Anja with an average velocity of 1.6m/s. The calculated flood and ebb currents also highlight a spatio-temporal dynamic; the flood current obtained in the Bridge in 2019 and 2020 were 0.019cm/s and 0.013cm/s respectively. The latter changes to 0.0056cm/s in Bona'Anja (spring tide of 2020). Similarly, the ebb current values for these two sampling periods were 0.013cm/s and 0.011cm/s for 2019 and 2020 respectively (Figure 7). The 0.011cm/s registered in 2020 in the Bridge later drop to 0.0024cm/s in Bona'Anja. A quick comparison of these two currents showed that the Wouri-Nkam channel of the Wouri estuary is flood dominance (i.e., flood currents are higher compare to ebb currents). The results also highlight that, from 12:30 to 3:30 pm, the water level in Bona'Anja was higher than that in the Bridge (Figure 7).

Relationship between hydro-morphometric and water quality parameters: The spearson correlation coefficient was performed to obtain the quantitative description of the relationship between the hydrological parameters and tide (Table 4). The results of this analysis showed that, in the Wouri Bridge, river discharge (outgoing flow)has a negative relation with salinity (r = -0.86), TDS (r = -0.91) conductivity (r = -90), hydrogen ions (r = -0.91) and temperature (r = -0.93). In Bona'Anja, these correlation coefficients changed to r = 0, r = 0.55, r = 0.40, r = -0.34 and r = -0.63 for Salinity, TDS, Conductivity, pH and temperature respectively. Indeed, while the correlation with

DO (r = 0.72) in the Bridge is being reduced to r = 0.53 in Bona'Anja, that of phosphates ions (r = 0.94) became inverted to negative (r = -0.74) in Bona'Anja. In the same way, water level showed a positive correlation of r = 0.71 with Salinity, TDS and Conductivity (Table 4). These good associations are reduced to non-significances relationships in Bona'Anja with correlation coefficients of r = 0, r = 0.34 and r = -0.03 accounting for Salinity, TDS and Conductivity respectively. These results also revealed that river discharges and tidal elevation have antagonistic effects on salinity, conductivity and TDS in the Bridge section.

The correlation coefficients between the monitored physical and chemical parameters were also computed to depict their various linkages. The result of this correlation matrix is presented in Table 5 (Bridge segment) and table 6 (Bona'Anja). In the Bridge (Table 5), Salinity, TDS and Conductivity all have a significant correlation link of r = 0.99 with each other. In addition to these values, the correlation between phosphates ions (ORP) with Salinity (r = 0.84), TDS (r = 0.83) and Conductivity (r = 0.84) are included to the set of significant correlations. All the other parameters did not show significant associations between each other. Inverse correlations were also noticed between DO with Salinity (r = -0.53) and TDS (r = -0.52). In Bona'Anja, salinity presented a valueless correlation with all the other parameters (table 6). Apart from the link between ORP with pH (r = 0.66) and Resistivity with TDS (r = -0.88) no significant relationship existed between the water quality parameters in Bona'Anja.

Tidal influence on the daily dynamic of water quality parameters: The changes in the water quality parameters that result from the daily variation of water level (tidal cycle) were noticed. The results of this high-frequency time-series measurements are presented in Figure 8 (2020 survey) and figure 9 (2019 survey). These results showed that the patterns of salinity, conductivity and TDS obtained were synchronized with the tidal elevation observed in the Bridge (Figures 8 and 9). However a deep analysis of these signals revealed a time delay in this co-evolution, for illustration, in the 2020 signals, flood tide begins around 3:00pm while the corresponding increase in salinity, conductivity and TDS appears around 4:00 pm indicating a time lag of about 1 hour (Figure 8). Similarly, in 2019, flooding started around 12:30am while salinity, conductivity and TDS responded to this rise in water level around 2:15 pm, indicating a longer time lag of about 1h15minutes (Figure 9). These results also highlight important changes in the water quality parameters within a semi-tidal cycle i.e., for a typical flood-ebb change, ranges values of 4.6 PSU, 8.5us/cm and 5.3mg/l in 2019 (Figure 8), and 6.73psu, 7.68us/cm and 3838mg/l in 2020 (Figure 9) were noticed for salinity, conductivity and TDS respectively. This synchronized semi-diurnal variability range (flood-ebb) was not observed in DO, pH and temperature (Figures 8 and 9). However, since these parameters are time-dependent, they presented typically daily fluctuations, different from the simultaneous hydro-tidal cycles observed for salinity, TDS and Conductivity. In the same way, Figure 10 presents the small scales dynamics every hour. In the Bridge, the maximum increase and decrease in water parameters after an hour were +1.5 and -0.9 PSU (salinity), +1250 and -750 mg/l (TDS) and +2.8 and -1.5 uS/cm (Conductivity), +0.4 and -.5 mg/l (DO), +3and -3.5 °C (Temperature) and +0.1and -0.3 (pH). These positive features (positive values) were synchronized with the increasing tide (flood) for TDS, Salinity and Conductivity in the Bridge. The above signatures were not noticed in Bona'Anja (blue line, Figures 8 and 10). In this segment, Salinity, Conductivity and TDS have a constant zero value throughout the day meaning that, the brackish water from the middle estuary does not reach this segment of the channel. This results also confirm that the tidal stage or elevation does not directly influence the dynamic of pH, Temperature and DO concentrations (Figures 8 and 10).

DISCUSSION

Longitudinaland temporal signature of water quality parameters: The daily snapshot of the monitored water quality parameters especially during spring tide conditions of May 2020 was presented in Figure 2.

Dissolved oxygen (DO): The spatial distribution of DO during the spring tide condition of May 2020 (Figure 2) revealed that the Wouri-nkam channel of the Wouri estuary was in a hypoxia state (Salinities < 2mg/l). This DO depletion could be explained by the dredging project (from Akwa nord to Bangue) implemented in 2020; this intense dredging could expose un ionized soil that demanded oxygen for its chemical reactions and consequently lowering the amount of available dissolved oxygen in water. This process could be aggravated by the domestic dumping, low river flow and poor atmospheric mixing. The anthropic activities of the Douala harbour couple to agricultural accomplishments around Bossamba and Bona'Anja could also influence the oxygen depletion observed in 2020 (Rabalais *et al.,* 2010). The decreasing trend observed during the flood could be due to the intrusion of a relatively more oxygenated brackish water while the pattern in ebb condition could be explained from the different microenvironments and their biological activities. The inter-spring tides comparison between the year 2019 and 2020 in the Bridge segment only (Table 2) showed good values of DO (max and mean values of 10 and 7.67 mg/l respectively) in the 2019 cruise, these values dropped to 2.3 and 1.45mg/l (DO depletion) in 2020 respectively (Table 2). The inter-spring reductionin DO could be related to increasing agriculture, more intense anthropic ballast water from the Harbour activities, non-renew of water masses and more intense anthropic pollution from the surrounding population. This observation comes to confirm that this channel is experiencing a continuous decline in water quality, which is considered as being deleterious for animal physiology (Gray *et al.,* 2002).

DO reveal a significant positive correlation only with river flow (r=0.72) in the Bridge (Table 5, 6 and 7) meaning that these two variables change in the same direction. A similar correlation has been observed in the Garonne and Dordogne estuaries by Lajaunie-Salla (2016). This correlation was poorly perceived in Bona'Anja (r=0.53), due to itsLimnic character. The good correlation between DO and river flow confirms that the estuary had a greater flow during the spring condition of May 2019 (resulting in better oxygenation) compared to 2020.

Hydrogen ions concentrations (pH): The longitudinal variation of the hydrogen ions concentrationsin the 2020 survey (Figure 2), revealed that the pH of water does not significantly change during ebb tide and this could be explained by little or no brackish water. However, the intrusion of brackish water during flood tide resulted in a typical pH zonation, i.e., an acidic upper zone from Ngombe to Bona'Anja (pH<7) and a basic lower zone from the Bridge to Yassem (pH>7). A similar result was reported by Fortune and Mauraud (2015). Table 4 of the inter spring signature in the Wouri Bridge showed that the spring tide condition of the year 2019 has greater basic properties (pH=9.5) compared to that of 2020 (pH=7.11). Also, their range values were 2.96 and 0.34 for 2019 and 2020 respectively signifying that the spring tide of May 2020 was more stable with fewer variations. This inter-spring comparison revealed continuous acidification that confirms the continuous degradation of this channel and this could be explained similarly as DO degradation. Regarding the various correlations (Tables 5, 6 and 7), pH only highlight a significant anti-correlation (r= -09.3) with river flow in the Bridge (table 5). This value reduces in intensity to r = -0.63 in Bona'Anja. This means that the pH values increase when river flow decreases and vice versa implying that high value in the Bona'Anja was due to lower river flow. These results are similar to those observed by Fortune and Mauraud (2015) working in the Darwin Harbour region and major estuarine arms in Australia.

Temperature: The water temperatures in the upper section of the Wouri estuary were high and varied little in either time or space (Figure 2). The ebb tide condition has relatively higher temperature values compared to flood tide. This result is similar to that obtained by Fortune and Mauraud (2015) and could be due to the lower volume of water present during ebb tides. During spring tide of May 2020 (Table 2), the differences between the max and the min temperature remained at 4.83 (30.89-26.08°C ±1.26). This temperature range reduces to 2.83 (32.09-29.26°C ±0.78) in 2019 revealing an inter-spring dynamic in temperatures. This situation could be explained from different atmospheric conditions between these two periods, asthe surface water temperature is a direct footprint of atmospheric forcings (Maes *et al.,* 2014). Apart from the correlation with river flow in the Bridge and Bona'Anja, temperature do not give any significant correlation with the other hydrological parameters. The significant inverse correlation (r= -0.93) obtained in the Bridge dropped to r= -0.63 in Bona'Anja (Table 4). This result clarifies that when river flow increases, temperature values deceases.

Salinity and TDS: The daily salinity showed higher values during flood compared to ebb tide condition. Also, the salinity distribution in this channel presented an axial horizontal gradient ranging from the maximum values (6.74psu) in the Bridge to null values (0psu) in the river end (from Bonalokan to Bona'Anja), indicating the upstream limits of the salinity intrusion length in the Wouri estuary (Figure 2). This observation highlight longitudinal zoning, i.e., the Oligo-haline zone ~~around~~ near Bonalokan and a Limnic zone from Yasem to Bona'Anja. This trends in salinity could be explained from river flow and estuarine bottom friction resulting from the changing bathymetry (Fond, 1954).

Regarding the Bridge only, the inter-spring analysis (table 2) showed that the salinity of water observed during the study periods varied between 0.1 and 4.7psu (May/2019) and from 0.01 to 6.67 PSU (May /-2020).

These salinities are greater than those predicted by Onguene, (2015) meaning the SYMPHONIE model under estimated the salinity values in the Wouri estuary. Also, the relatively higher salinities values of 2020 despite the weaker tidal range could be explained by the fact that, 2020 was a relatively dry year (more sunny days and lesser precipitations) with more evaporation and evapotranspiration from mangrove forests. Oppositely, In Bona'Anja (30 km away), no salinity was registered. The null salinity in Bana'Anja could be explained from the fact that salinity excursion limit is found in Yasem (15kilometers from Bona'Anja). Salinity also give significant correlations with related parameters (table 5) like conductivity (r= 0.99) total dissolved solutes (r = 0.99) and river discharge (r = -0.86). The correlations coefficients with the water level in the Wouri Bridge gave r = 0.71, signifying that these variables were proportional related when considering the combined datasets for 2019 and 2020. According to their inter-dependent, this correlation value was expected to be higher, however, the relatively low correlation (r = 0.71) observed compared to the synchronized signal could be due to the fact that there is a time lag between the water level and corresponding response of the estuarine properties. Finally, the highest TDS content observed in 2020 (Figures 8 and 9) may be due to floating materials like fine silt and detritus that could also explain the previously observed the oxygen depletion of 2020. This confirmed the observations made by Dwivedi et., (2012).

Description of the Bathymetric profile (hypsometric parameters): The bathymetry profile illustrates a decreasing trend from the ~~b~~ Bridge to Bona'Anja, with very pronounces fluctuations of raise and fall in depth (Figure 3). The deepest sections was the Bridge (-5m) > Bangue (-4.6m) > Bonangang (-4.4m) while the shallow once were Bona'Anja (-1.6m) > Ngombe (-1.8m) > Bonapea (-2.1m). This decreasing trend could be explained by the continuous deposition of sediments in the upstream section as a result of the decreasing tidal prism (volumes) with decreasing geomorphological parameters (Prandle, 2004). A similar observation was made in this channel by Besack *et al.,* (2020). According to Zhang *et al.,* (2010), this channel is considered as a shallow-water estuary because it bathymetry does not exceed -5m depth. Looking at the Bridge, the observed depth is in the same range with that predicted by Onguene, (2015) using the 3-D SYMPHONIE model. The fluctuating topography observed in this channel (Figure 3) could be due to sand excavation activities (the principal activity of the local population). Similar results have been obtained by Luo *et al.,* (2007) while studying the effects of sand excavation on the hydrology of the Pearl River estuary.

Signature of Surface currents velocity and discharge volumes: The high-frequency time-series sampling of surface currents in the Bridge and Bona'Anja enable us to depict small scales features in the velocity of surface current between these two ends of the channel. The results obtained in figure 6 showed that, after a semi-diurnal (half a day) period of observation, both segments displayed distinct current profile with amplitudes of changes of about 1.2m/s in the Bridge and 0.23m/s in Bona'Anja. This greater current intensity in the Bridge section could be due to its exposure to a greater tidal influence couple to its funnel effect.

The minimum values alongside these amplitudes were 0m/s (observed in the Bridge at 09:30 am indicate the high water slake) and 0.2m/s in Bona'Anja. The high water slakes effect (null current velocity) was not observed in Bona'Anja due to its Limnic nature (riverine domination, with a unidirectional current flow throughout the day). In addition to this observation, the Bridge was characterized by a bidirectional flow while the flow in Bona'Anja remains unidirectional throughout the periods of observation. This difference in hydrological breathing could be explained by the different influences of tidal parameters between these two segments. Other factors such as solar radiation, air temperature and evapotranspiration processes along or near estuaries channels could also play a role of inducing different daily dynamic between different segments of the same estuary (Gribovszki *et al.,* 2010). This arrived at a concluding result that, the Bridge segment is a mixed tidal-fluvial regime or mixed tidal-fluvial influenced while Bona'Anja is a fluvial dominated, tidally influenced regime (Sandbach, 2012). The spatial distribution of surface currents during flood and ebb tide conditions (figure 4) revealed a decreasing horizontal trend (red line) during ebb tide and a reversing trend during flood tide (from the Bridge to Yassem) (blue line). This means that the entire channel highlighted a decreasing horizontal outward flow during ebb tide condition with a maximum velocity of 1.2m/s in the Bridge and a minimum of 0.34 m/s in Bona'Anja. On the other hand, the flood condition highlights an alternation of direction between it lower and upper section with an upward flow in the lower section (estuary dominated) and outward flow in the upper part (riverine domination). During Flood tide conditions, the maximum surface velocity (-0.66 m/s) was observed in the Bridge while the minimum values (-0.22 m/s) was recorded in Yassem (17km from the Bridge) indicating not only the current inversion limit but also the limit of landward sediments transport in the Wouri estuary. The result obtained in this work fall in the same range as those observed by Medeiros and Kjerfve, (1993). These authors obtained values ranging from 0.2 to 2 m/s according to the position in the estuary when studying the hydrology of a tropical estuarine system (Itamarac, Brazil). The inversion of current direction observed during the flood condition of spring tide at Yassem could be explained by the tidal damping through the loss of tidal energy due to changing bathymetric and increasing friction (Medeiros and Kjerfve, 1993). This surface current inversion is similar to that observed in the Jaguaribe River estuary, Brazil by Diaz *et al.,* 2009. These maximum value in the Bridge could be due to the funnelling effect (changing channel width) causing shoaling and its position relative to the mouth of the estuary. The absence of current inversion in Bona'Anja could be related to its river domination. The discharge volumes of water computed during flood and ebb tide conditions revealed similar trends as surface current (Figure 5). The high amount of brackish water entering (red line) and leaving (blue line) this channel (through the Bridge) could be due to the greater cross-sectional area of this point and couple to its funnel shape (red line).

Tidal dynamic and water level evolution: The time series curves of tidal elevation (Figure 7) showed that, around the Bridge, the amplitude of tidal elevation was 2.7m in 2019 and reduced to 2.3m in 2020 signifying that the spring tide of May 2019 was more intense compared to that of the year 2020. This inter-spring dynamic could be explained from the fact that tide elevation in an estuary is influenced by geometry, bottom topography, meteorological forcings and river discharge which were not the same despite the similar tidal regime during these two periods (Zhang *et al.,* 2010). The analysis of figure 7comparing the water level in the Bridge and Bona'Anja, revealed a tidal distortion; i.e., the tidal range losses about 74% of its amplitude and reduces from 2.3m in the Bridge (mesotidal properties) to 0.6m in Bona'Anja (micro-tidal characters). This difference in tidal range between the Bridge and Bona'Anja conferred a hypo-synchronous character to this channel (Besack *et al., 2020*); the bottom friction offset the influence of convergence causing a continuous upstream decrease in tidal range. Also, the tidal wave takes about 5hours to travel the 30km from the Bridge to bona'Anja with an average velocity of 1.6m/s. The calculated flood and ebb currents also highlight a Spatio-temporal dynamic; the flood current obtained in the Bridge in 2019 and 2020 were 0.019cm/s and 0.013cm/s respectively. The latter changes to 0.0056cm/s in Bona'Anja, 30 km away from the Bridge. Similarly, the Ebb current values for these two sampling periods were 0.013cm/s and 0.011cm/s for 2019 and 2020 respectively. The 0.011cm/s registered in 2020 in the Bridge later dropped to 0.0024cm/s in Bona'Anja. These values showed that this channel is flooded dominant and this could be explained from the different channel configuration and basin hypsometry (Salles, 2011). The combination of these factors couple to the tidal velocity asymmetry could account for the landward transport of sediments encounter after Yassem (more than 17km away from the Bridge) and the corresponding reduction in bathymetry (Salles,2011; Chu *et al.,*2015 and Guo *et al.,* 2016).

Semi-diurnal effect on the hydrological signature: The effect of a semi-diurnal tide on the dynamic of the monitored hydrological parameters was finally investigated. This study revealed a semi-diurnal signal between water elevation and other parameters such as salinity, conductivity and TDS during the two spring conditions investigated (Figures 8 and 9). The correlation coefficients (r=0.71) obtained between water level and the above parameters (Table 5) confirms this synchronized evolution. However a deep analysis of the evolution of these signals revealed a time delay, for illustration, in the 2020 signals, flood tide begins around 3:00pm while the corresponding increase in salinity, conductivity and TDS appears around 4:00pm indicating a time lag of about 1 hour. These time lags could be explained by the fact that there is a minimal prism required to create the effect marine effect in the Oligo-haline section (Birdge, Akwa nord, Bangue and sometimes Bonalokan) of this channel; before this volume of water (prism) is reach, increase in water level do not have the corresponding effect on salinity, conductivity and TDS. The semi-diurnal signal (flood-ebb dynamic) was not observed in dissolved Oxygen, pH and temperature time series, they presented typically daily fluctuations, different from the simultaneous hydro-tidal cycles observed for salinity, TDS and Conductivity. The sub-daily thermal dynamic observed (Figures 8 and 9) was connected to daily radiation pictures; with peaks values around 1:30 – 2:00 pm. Similarly dissolved DO could be footprint of daily (hourly) photosynthesis. Salinity, Conductivity and TDS have a constant zero value throughout the day in Bona'Anja (Figure 9) meaning that, the brackish water from the middle estuary does not reach this segment of the channel. This situation could be attributed to the dominant river character of Bona'Anja (about 30 km away from the Bridge). The small scales features (Figure 10) observed in the Bridge (red bars) confirms its more dynamic nature from the incoming brackish water from the middle estuary.

Conclusion and recommendation

The hydrological variables of the upper section of the Wouri-Nkam channel of the Cameroon estuary were monitored during spring tide conditions to investigate short term fluctuations that may characterize this hydro-ecological system. The spatial evolution, time-series dynamics and the effect of spring tide on the hydrological variables were explored. The temporal and spatial distribution of DO revealed a continuous depletion with relatively higher values during ~~the~~ flood tide. Salinity displays a horizontal gradient ranging from the Bridge to Bona'Anja, with a null (0 PSU) around Bonalokan (km35.31; i.e., 07km from the Bridge) indicating the limit of the tidal intrusion. The outcome of this investigation revealed a bidirectional horizontal current profile from the Bridge to Ngombe (20km from the Bridge and 47km from the mouth) on a daily scale. The bathymetry profile illustrates a decreasing trend from the Bridge to Bona'Anja, with very pronounces fluctuations of raise and fall in depth. The time series curves of tidal elevation showed that, the spring tide of May 2019 was more intense compared to that of the year 2020 but paradoxally, 2020 has relatively greater salinity values. During each tidal cycle, the salinity, conductivity and TDS in the Bridge very synchronously (despite the time lag of 1hour) with the stage of tidal elevation. The above signatures were not noticed in Bona'Anja. This study concluded that the lower boundary (Bridge section) with it Oligo haline character (influence by saline water) is more dynamic than the upper limnic section (from Bangue to Bona'Anja) of the channel.

The immediate recommendation from this study is to increase awareness about the negative impact of a continuous depletion (increase anoxia and acidification) of the water quality parameter. The local population of the various neighbourhoods along this channel should participate in the management of this ecosystem; most of the wastes from the surrounding neighbourhoods and plantations should be treated before being deposit in the estuarine water, the Center of tropical Aquaculture (CAT) in Bona'Anja should use the axial saline intrusion dynamic during the selection of their potential sites for fresh or brackish species farming. The similar result should be used in the mapping of sand excavation site especially for immediate construction purposes. As an outlook, we look forward to replicating this study to take into account all the lunar tide vibrations, seasonal and inter-annual variations. Lastly, constructions activities should be prohibit (at least 500meter away from the line of high tide) along the estuary banks, right up to Ngombe (18km from the Bridge, representing the limit of the bidirectional flow).

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