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Influence of tidal regimes in relation to industrial activities on the hydrodynamics of the Calabar River system in Southern Nigeria

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Abstract
The Cross River system is formed from numerous tributaries arising from the Western slopes of the Cameroon Mountains which have two spurs into Nigeria as the Oban Hills in the south and the Obudu Hills in the North. A field study was conducted during a single expedition at designated locations to study the influence of tidal regimes in relation to industrial activities on hydrodynamics of Cross River system between 10th and 11th August, 2009 during the high and low tidal regimes using the Institute of Oceanography Research Vessel "Plankton Fisher". The locations used for the studies were CALCEMCO (now UNICEM) jetty, Intels Jetty (left and right Flanks), Calabar/Creek Town entry route, TINAPA Jetty, Adiabo Bridge and Adiabo-Okurikang (control location). River depths and flow velocity were taken in-situ along designated stations using an automated eco-sounding device (for depth), and stop-watch and un-juiced orange fruit as floater (for flow velocity). The choice of stations was based on discharge rate, flow direction, absence of impediment to flow, depth, *ab initio.* These locations were, however, duly geo-referenced. During high tide, velocity values ranged from 0.01 and 1.42ms^{-1}. Highest velocity value of 1.42 ms^{-1} was recorded at Adiabo Bridge with the lowest value at Adiabo-Okurikang (control point). Generally, there were marked variations in velocity of the water current during the survey. Conversely, during low tide, water current velocity ranged between 0.01 and 1.11ms^{-1}. Least velocity value of 0.01ms^{-1} was recorded at the left flank of Intel Jetty and Tinapa Jetty, respectively. This was followed by values of 0.03ms^{-1}, 0.14ms^{-1}, 0.23ms^{-1} and 0.35ms^{-1} at Adiabo-Okurikang, CALCEMCO jetty (UNICEM), Calabar/Creek Town entry route and Intels jetty (right flank), respectively. The study recommends the need for appropriate measures on tidal regime management for enhanced ecosystem functioning of the Cross River System.

Keywords: Hydrodynamics, High Tide, Low Tide, Calabar River system, Nigeria.

1. Introduction

Cross River is the main river in southeastern Nigeria and gives its name to Cross River State. It flows through swampy rainforest with numerous creeks and forms confluence with the Calabar River Moses, [11]. The Cross River system is formed from numerous tributaries arising from the western slopes of the Cameroon Mountains which have two spurs into Nigeria as the Oban Hills in the south and the Obudu Hills in the north (Enplan Group Consulting Engineers, [7]. The whole Cross River system lies approximately between longitudes 7°30'E and 10°00'E and latitudes 4ºN and 8ºN. The river basin covers an area of 54,000km^2 of which 14,000km^2 lies in the Republic of Cameroon, while the remainder lies in Nigeria which Calabar, Cross River State forms a part Moses, [11]. The climate of the river area is that of tropical rain forest. Temperature variations within the basin are between (27.5 °C – 35 °C maximum and 22 ºC - 24.0 °C minimum). The relative humidity is high throughout the year. Practically in the coastal area, 93% has been recorded in the Calabar area of the river during peak rainy period Moses, [11]. During this time, the water leveled rises with the addition of run-offs (Enplan Group Consulting Engineers, [7]. Moses, [11].

Studies of hydrodynamics of aquatic ecosystems provide vital information for river basin management for such studies help to interpret the formation of river morphology and the socio-economic development of the area in addition to the habitual diversity status which invariably are consequential to industrial and anthropogenic activities in the river system (Marmer, [10]; Zhang *et al.*, [16]. In contemporary river systems history, frequent changes in river systems associated with industrial developments on the coastal areas have been reported to exert tremendous negative impacts on the ecology of the river system (Teague *et al.,* [13]; Zhang *et al.,* [16]. River flow/discharge is the volume of water flowing past a fixed point in a fixed unit of time. Water current velocity changes with season, slope and depth of river and interventions of physical structures such as dams and bridge pillars (Grant & Tingle, [8]. Water velocity has a profound effect on physic-chemistry, the composition of a river bed (sand, silt and related materials) and the ability of invertebrates to keep a foothold, respire and feed (Grant & Tingle, [8]; Chanson *et al.,* [4]; Trevethan *et al.,* [14].

Variable flows are also known to have a far greater impact on fisheries, apart from that on benthic populations and other ecological settings in water bodies Chuang & Wiseman, [5]; Cochrane & Kelly, [6]; Walker *et al.,* [15]. Water movement has long been acknowledged as one of the prime factors regulating the growth and distribution of submerged aquatic plants in aquatic ecosystems and that changes in water flow or velocity can alter the biomass and species composition generally of the ecosystem. In general, water current velocity and depth is an important factor regulating the distribution and occurrence of biotic life during the varied and different tidal regimes in the aquatic environment Hence, the need to undertake studies on the hydrodynamics of water bodies, especially where industrial activities are being intensively carried out as in the Cross River system, Calabar-Nigeria Chambers *et al.,* [3].

The selected locations were CALCEMCO (now UNICEM) jetty, Intels Jetty (left and right Flanks), Calabar/Creek Town entry route, TINAPA jetty, Adiabo Bridge and Adiabo-Okurikang (control location). These locations were, however, duly geo-referenced (Table 1).

2.1.1 Velocity Measurements

The velocity of water current at each of the designated locations was measured by floating object method recommended by Grant & Tingle [8]. This method involved timing a floating object (usually orange) over a known distance of 10 meters using a stop-watch (Plate 2). Five (5) repeated readings were made at each location from which a mean value was determined to ensure accuracy of readings as shown in Table 1. Velocity values were recorded in meters per second (m/s).

Plate 1: Taking of velocity reading during the study.

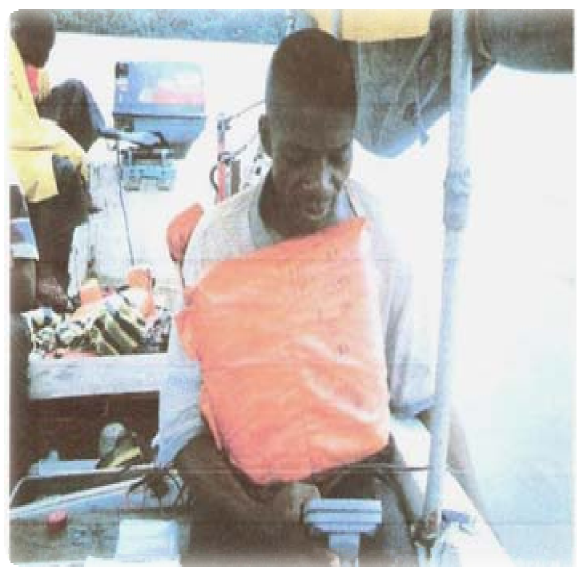

Plate 2: Taking of depth measurement during the study.

2.1.2 Depth Measurements

These were recorded using a digital electronic eco-sounding device model: EAGLE CUDA Tm//68 USA. Essentially, five (5) different readings were taken at each location/point and a mean reading determined in meters Table 1).

2.1.3 Geographical Locations

These were determined by the use of a Global Position system device (GPS) model: GPS 315 MAGELLAN USA. Only single readings were obtained during the two respective tidal phases in latitudes and longitudes (Table 1).

2.2 Water Current Velocity

2.2.1 High Tide

The water current velocity values at the different locations are shown in Table 1. During high tide, velocity values ranged from 0.01 and 1.42ms^{-1}. Highest velocity value of 1.42ms^{-1} was recorded at Adiabo Bridge with the lowest value at Adiabo-Okurikang (control point). Generally, there were marked variations in velocity of the water current during the survey. For instance, at CALCEMCO jetty (UNICEM), velocity was 0.08ms^{-1}, 0.15ms^{-1} and 0.45ms^{-1}, respectively at the left and right flanks of Intels Jetty; 0.03ms^{-1} at Tinapa Jetty, 1.42ms^{-1} at Adiabo Bridge and 0.01ms^{-1} at Adiabo- Okurikang (control station).

2.2.2 Low Tide

During low tide, water current velocity ranged between 0.01 and 1.11ms^{-1}. Least velocity value of 0.01ms-^{I} was recorded at the left flank of Intel jetty and Tinapa Jetty, respectively. This was followed by a value of 0.3ms^{-1}, 0.I4ms^{-l}, 0.23ms^{-1} and 0.35ms^{-1} at Adiabo-Okurikang, CALCEMCO Jetty (UNICEM), Calabar/Creek Town entry route and Intels Jetty (right flank), respectively (Table I, Figure 2).

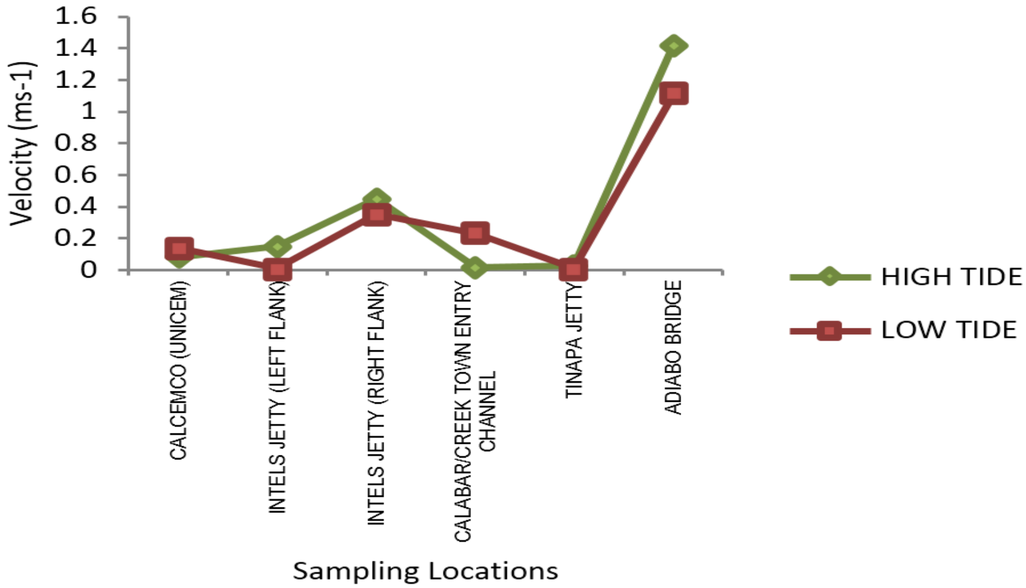

Fig 2: Velocity variations in relation to tidal regime during the period of study in the Calabar River System – Nigeria.

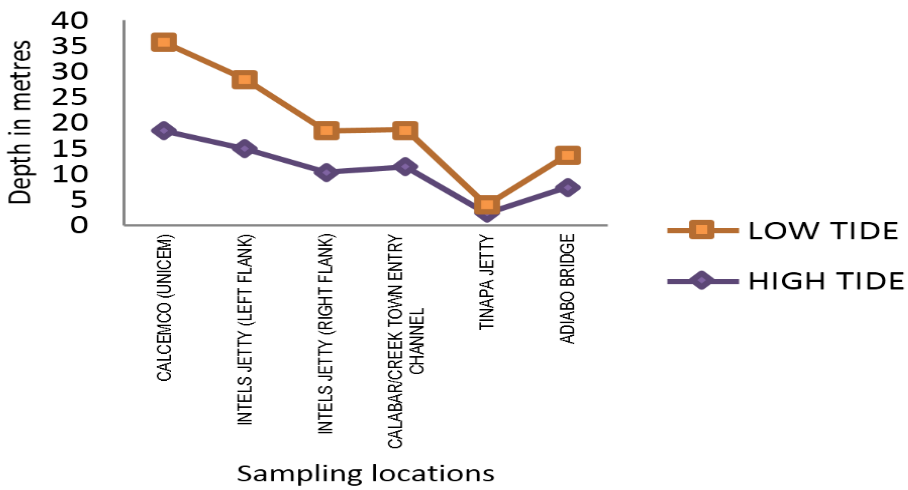

Fig 3: Depth variations in relation to tidal regime during the period of study in the Calabar River System – Nigeria.

Table 1: Hydrodynamics parameters of the sampled locations in the Calabar River systems, Cross River State – Nigeria.

Location	GPS Coordinates	High tide			GPS Coordinates	Low tide		
		Depth (m)	Mean velocity (m/s)	Time of reading (GMT) (hrs)		Depth (m)	Mean velocity (m/s)	Time of reading (GMT) (hrs)
CALCEMCO (UNICEM)	04°58.829'N 008°19.389'E	18.40 (40 ASL)	0.08	09.38	04°58.829'N 008°19.389'E	17.20 (40 ASL)	0.14	01.22
INTELS JETTY (LEFT FLANK)	05°0.747'N 008°18.951'E	14.9 (40 ASL)	0.15	10.29	05°0.747'N 008°18.951'E	13.49 (40 ASL)	0.01	14.20
INTELS JETTY (RIGHT FLANK)	05°0.528'N 008°18.981'E	10.30 (3 ASL)	0.45	10.38	05°0.528'N 008°18.981'E	8.14 (3 ASL)	0.35	14.28
CALABAR/CREEK TOWN ENTRY CHANNEL	05°0.012'N 008°17.687'E	11.30 (20 ASL)	0.02	11.2	05°0.012'N 008°17.687'E	7.3 (40 ASL)	0.23	15.22
TINAPA JETTY	05°2.786'N 008°19.043'E	2.3 (39 ASL)	0.03	12.15	05°2.786'N 008°19.043'E	1.6	0.01	16.18
ADIABO BRIDGE	05°3.277'N 008°18.207'E	7.40 (6 ASL)	1.42	13.05	05°3.277'N 008°18.207'E	6.26	1.11	17.03
ADIABO-OKURIKANG (CONTROL)	05°4.211'N 008°15.456'E	5.0 (10 ASL)	0.01	13.35	05°4.211'N 008°15.456'E	2.48 (10 ASL)	0.03	17.50

Source: Field Survey *in-situ* Data (2009).

The geographical coordinates were mapped out and digitally plotted to show the geographical spread of the sampled areas (Fig 1).

Fig 1: Map of Calabar River system, Southeast Nigeria showing sampling points

2.3 Results

2.3.1 High tide

Highest depth of 18.40m was recorded at CALCEMCO jetty (UNICEM) during high tide while the lowest depth of 2.3m was recorded at Tinapa jetty. A depth of 14.90m, 11.30m, 10.30m, 7.40m and 5.0m were respectively recorded at the left flank of Intels Jetty, Calabar/Creek Town entry route, Intels Jetty (right flank), Adiabo Bridge and Adiabo-Okurikang (Control point) (Table 1).

2.3.2 Low Tide

Low tide depths were observed to range between 1.6 and 17.20m. At Tinapa Jetty, a depth of 1.6m was recorded, while a depth of 2.48m, 6.26m, 7.3m, 8.14m, 13.49m and 17.20m were respectively recorded at Adiabo-Okurikang, Adiabo Bridge, Intels jetty (right and left flanks) and jetty (Table I, Figure 3).

3. Discussion

Urbanization and industrial activities in some sections of the Cross River system, Calabar-Nigeria, have resulted in faster surface runoffs and Peak River flow rise and fall during high and low tides in the river system than previously occurred Enplan Group Consulting Engineers, [7]; Moses, [11]. In river systems where industrial activities and building of structural facilities have been reported to cause increased water flows and reduced/increased depth due to dredging Akpan, [1]; Statzner *et al.*, [12]; Chambers *et al.*, [3]. There have been reports on reduced nutrient concentration, plankton community structure and reduction in fish catches as a result of increased water velocity and depth, Akpan, [1]; Walke *et al.*, [15].

The results of the study revealed that water current velocity is dependent on depth as seen at CALCEMCO jetty (UNICEM) where a depth of 18.40m caused a velocity of 0.08ms^{-1} during high tide and a depth of 7.20m which produced a velocity of 0.14ms^{-1} at low tide. According to Zhang *et al.* [16], maximum flow velocity is usually related to the deeper water depth, Jut that irregular water column distribution of flow velocity often results in vortices current associated with river knots which during this study, can be Linked to physical structures impeding free flow of water. This phenomenon was observed at Adiabo Bridge. In the central Californian River, Teague *et al.* [13] recorded maximum velocity of 0.8ms^{-l} and associated it to tidally driven factors with flow reversals every 6 hours. During this study a maximum velocity of 1.42ms^{-l} and 1.11ms^{-l} were respectively recorded during high tide and low tides at Adiabo Bridge. At CALCEMCO jetty (UNICEM), where little or no activity seems to exist, a velocity of 0.08ms^{-l} at high tide and 0.14 ms^{-1} at low tide were recorded. These values are usually not associated with the presence of physical structure, rather with depth Zhang *et al.*, [16].

Water current velocity values are indicative of the dynamic nature of the river systems, especially at locations where physical structures are present and depths tremendous Balachandran *et al.*, [2]. At locations where velocity is high in an aquatic system, biotic life are unstable, as it is susceptible to lack of food and balanced ecological influences (Teaque *et al.*, [14]; Akpan, [1]. This was the case at Adiabo Bridge and Intels Jetty.

Similarly, where depths are shallow, negative impacts have been ~ported on biotic life as most of them are negatively affected by the solar radiation intensity. Benthic community, fish and other invertebrate organisms are usually the most seriously affected (Trevethan *et al.*, [14]; Chuang & Wiseman, [5], Cochrane & Kelly, [6], Walker *et al.*, [15] and Akpan, [1]. This may be the expected outcome at Tinapa Jetty and Adiabo-Okurikang in the present study.

4. Summary and Conclusions
Many aspects of the ecology of the Cross River system may be affected by the present observed depths and water velocities, particularly at the sampled locations. Biotic population in any ecological system depends on the interplay of the physical and chemical factors of the system. With the continuous alteration in these factors due to human influences, the long term effects, as one would expect, falls back adversely on the water quality, biotic life and food web and consequently human well-being in the entire area.

5. Recommendations
Based on the results of the present study, it is recommended that a time series and articulated monitoring be put in place by the operating companies. This will, however, require the cooperation of researchers, Environmental Protection Agencies (EPA), Non-Governmental Organizations (NGOs) and Government Organizations. By the words of Grigg, [9], "Managing the water quality of estuaries (and river systems) requires unique action plans based on good science".

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